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*Generating Electric Power in
the Pacific Northwest*

Implications of Alternative Technologies

*Christopher G. Pernin, Mark A. Bernstein, Andrea
Mejia, Howard Shih, Fred Rueter, Wilbur Steger*

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Preface

This report examines the implications of using alternative power-generation technologies to meet future energy demands in the Pacific Northwest region of the United States. The results are intended to inform both policymakers and the general public and to provide useful information for policymakers planning for energy needs who must consider the role of energy efficiency and renewable-energy programs in the future.

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Summary

The Pacific Northwest faces some critical energy issues over the next 20 years. There is significant uncertainty about energy supplies, energy prices, and the implications of competitive energy markets. Therefore, as energy demands continue to rise, it is important for the states in the region to understand the risks and opportunities of different energy supply and demand options. This report addresses issues in electricity supply and demand for four states in the Pacific Northwest: Idaho, Montana, Oregon, and Washington.

For much of the past 50 years, these states have relied heavily on hydroelectric power to meet their energy needs, and this inexpensive electricity has helped keep electricity rates low in the region, compared with the rest of the United States. However, the region cannot add much new hydroelectric capacity, so increasing demands for electricity in the future will have to be met by other sources. It is expected that the bulk of new electricity-generating capacity will come from natural-gas-fired power plants. While the combined share of electricity generated by hydroelectric and natural-gas-fired plants is expected to remain the same through 2010 (together, they provide 86 percent of the capacity in the region, the remainder being provided primarily by coal and nuclear plants), the proportion generated by natural gas will rise dramatically. Table S.1 summarizes the shares of current and future expected generating capacity in the region. The changes in the shares provided by the two major sources will have a number of consequences for the states in the region.

Table S.1
Shares of Current and Future Generating Capacity
Provided by Hydroelectricity and Natural-Gas-Fired
Combined-Cycle Generation
(percent)

Source	Year	
	2000	2010 (forecast)
Hydroelectricity	82	64
Natural gas	4	22

SOURCE: Energy Information Administration (EIA) forecast from *Annual Energy Outlook 2002* (adapted from EIA, 2002c).

While natural-gas plants are efficient and relatively inexpensive to operate, they are more expensive than the existing hydroelectric infrastructure; therefore, electricity rates will tend to be higher in the future. In terms of air pollution, natural-gas-fired plants are cleaner than oil- or coal-burning facilities, but they will still add emissions to the region, including precursors to local pollution as well as greenhouse gases.

Uncertainties and Risks in the Electricity Portfolio

Hydroelectricity in the Pacific Northwest has significant capacity uncertainties. The amount of hydroelectric power generated in any one year depends on the amount of rainfall in the region. Twenty percent swings in energy generation between wet and dry years are not unheard of. From a business standpoint, this uncertainty presents concerns because it affects costs.

Dams are a threat to the well-being of native fish populations, with dam construction particularly affecting wild salmon populations, so removal of the four lower Snake River dams has been discussed. Removing the dams could aid in restoring fish populations but would reduce the hydroelectric capacity in the region.

Uncertainties are also associated with the future price of natural gas and the future capability to supply gas to the region. It is therefore important for policymakers to examine the potential of alternative technologies and policies to help hedge against potential price and supply volatility. The growth in demand for natural gas could be moderated by increasing the diversity of supply sources, and the growth of electricity demand could be moderated by increasing energy efficiency. The electricity portfolio does not need to have an equal percentage of different alternatives, but reducing the 86 percent share of hydroelectric power and natural-gas-fired combined-cycle generation on the margin could help reduce risk and uncertainty.

One option would be to increase the share of supply sources that have less future price uncertainty, for example, renewable technologies such as wind and solar power. While renewable-generation technologies can be more expensive than natural-gas-fired generation, adding renewable generation into the national electric system could reduce pressure on future natural-gas prices. The EIA estimates that by 2020, natural-gas prices could be 5 to 10 percent lower with renewables than they are forecast to be without renewables (EIA, 2002a). The EIA also notes that with 10 percent of generation being supplied by renewable

sources, the reductions in gas prices would nearly outweigh the extra costs of renewable generation.

Another option would be to reduce the growth of electricity demand by improving energy use in buildings and developing more efficient electricity-using appliances. Moderating future demand would reduce the need for new electricity-generating capacity and reduce growth in natural-gas use.

Energy-intensive industries (primarily aluminum) that consume a significant amount of power in the Northwest and rely on long-term, low-cost contracts purchased directly from the Bonneville Power Administration (BPA) and other suppliers of bulk electric power are particularly affected by the allocation of cost-based federal hydroelectric power.¹ There has been considerable debate about whether these industries should continue to receive preferential prices for electricity.

Assessing the Impacts of Different Energy-Generation Options

This report addresses the macroeconomic impacts of options that would diversify the Pacific Northwest's electricity portfolio and may help hedge against uncertainties in natural-gas prices and supplies. The Policy Insight Model developed by Regional Economic Models, Inc. (REMI) is used to estimate the economic and net-employment impacts of including more renewable-generation options (wind and solar power) and more energy efficiency in the electricity mix of the Pacific Northwest. Three scenarios are compared against a base case modeled after the EIA forecast for the region:

- Shifting 20 percent of future natural-gas-fired generating capacity to energy efficiency and/or renewable generation (wind and/or solar power).
- Replacing the electricity produced by the lower Snake River dams with combinations of natural-gas-fueled generation, energy efficiency, and wind power.
- Replacing the electricity needed by the direct-service industries (DSIs) with energy efficiency.

¹These industries have recently received a partial renewal of those contracts for an additional five years, from 2001 to 2006.

Results and Conclusions

It is concluded that diversifying the electricity mix in the Pacific Northwest is likely to have little impact on the economy. In some cases, there is a slight negative impact, and in some cases, a slight positive impact. Figure S.1 shows the impact on gross regional product of replacing 20 percent of future *new* natural-gas generation with combinations of energy efficiency and renewable generation. Three options are shown in the figure. The ranges reflect different input assumptions: The lower bound assumes moderate gas prices and conservative assumptions about the costs of renewable generation and energy efficiency. The upper bound assumes rising gas prices and improved technologies for renewable generation and energy efficiency. The range of the impacts is small, from -0.2 percent to +0.2 percent of gross regional product.

Displacing a portion of the future natural-gas-fired capacity would have environmental as well as economic effects. If 20 percent of the expected additions of natural-gas combined-cycle capacity were replaced with renewable-generation alternatives that produced no emissions, the amount of carbon dioxide (CO₂) emissions displaced by 2020 would be about the same as the total emissions produced in the region in 1998 (approximately 42,000 kt). These changes would be accompanied by reductions in sulfur dioxide (SO₂) and

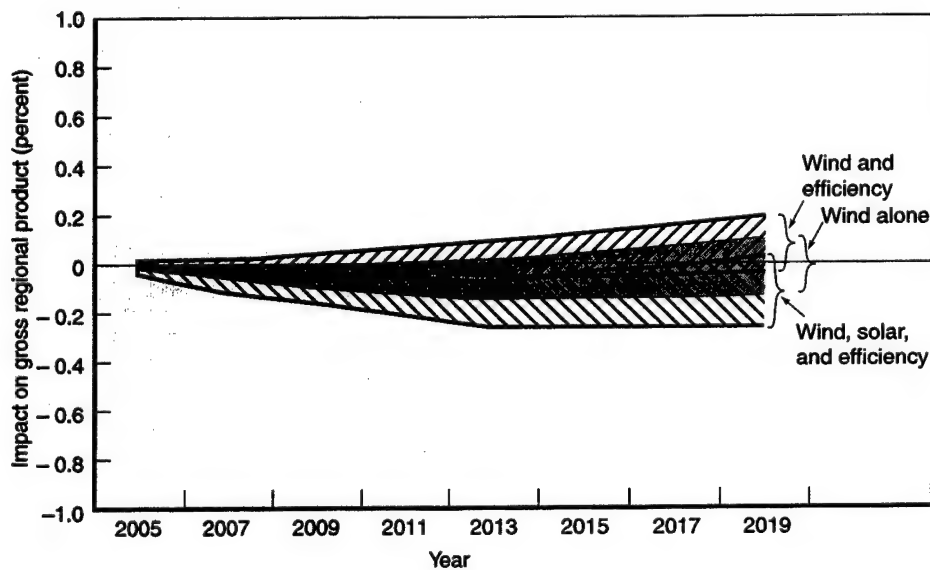


Figure S.1—Economic Impact of Replacing 20 Percent of Future Natural-Gas Capacity with Renewable Generation and Energy Efficiency

nitrogen oxides (NO_x) emissions that would be felt over the entire Pacific Northwest region.

The lower Snake River dams could also be replaced with alternatives without creating negative economic consequences; for some options, as shown in Figure S.2, their replacement could produce positive net employment in the region. Finally, investing in enough energy efficiency to equal the demand of the DSIs could result in positive economic impacts, potentially adding from 0.3 to 0.6 percent to the gross regional product by 2020.

In summary, the electricity portfolio could be diversified through efficiency and renewables without much impact on the economy, either positive or negative. Diversification could therefore provide an opportunity to hedge against future volatility in natural-gas prices and supply and hydroelectric production, while also providing other benefits to the region, including environmental benefits.

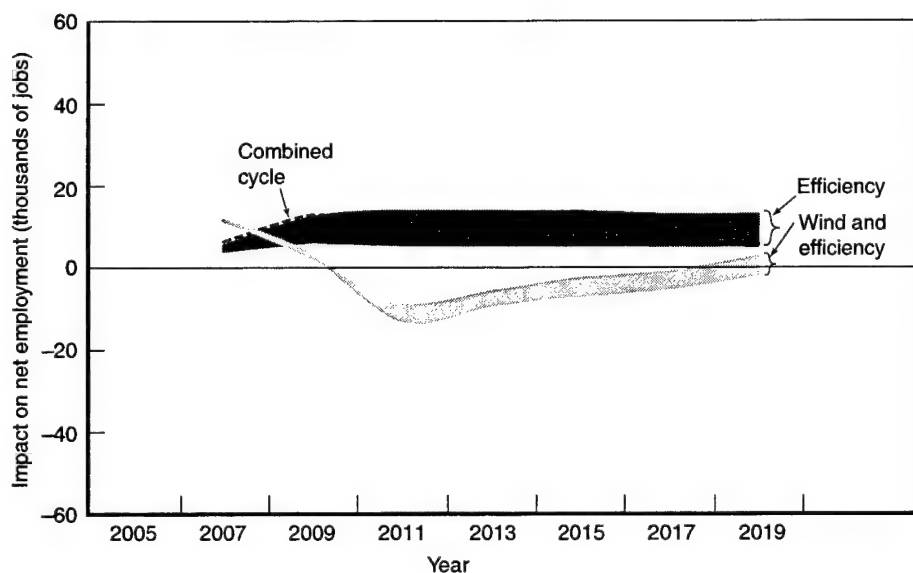


Figure S.2—Impacts on Net Employment of Replacing the Four Lower Snake River Dams with Energy Efficiency, a Combination of Wind Power and Efficiency, and Combined-Cycle Generation

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Acronyms and Abbreviations

aMW	average megawatts
BOR	Bureau of Reclamation
BPA	Bonneville Power Administration
Btu	British thermal unit
CGE	computable general equilibrium
CO ₂	carbon dioxide
DSI	direct-services industry
EIA	Energy Information Administration
EPRI	Electrical Power Research Institute
FCRPS	Federal Columbia River Power System
FERC	Federal Energy Regulatory Commission
GW	gigawatt
IMPLAN	impact analysis for planning
kg	kilogram
kt	kiloton
kWh	kilowatt-hour
mcf	million cubic feet
MW	megawatt
MWh	megawatt-hour
NED	national economic development
NO _x	nitrogen oxides
NWPP	Northwest Power Pool
O&M	operations and maintenance
OMRR&R	operations, maintenance, repair, replacement, and rehabilitation
REMI	Regional Economic Models, Inc.
RPC	regional purchase coefficient
SIC	standard industrial classification
SO ₂	sulfur dioxide
W	watt

1. Introduction

In the Pacific Northwest region of the United States (which comprises Washington, Oregon, Idaho, and Montana), rivers are abundant, and most electricity—82 percent of installed capacity¹ in 1999, according to the Energy Information Administration (EIA)—is generated from hydroelectric plants. This study considers the implications of meeting future regional energy needs with alternative energy sources.

Defining the Problem

The region's dependence on hydropower creates several potential problems. First, the power supply is highly variable, depending on the amount of rainfall in the region, and this variability affects costs. The variability of supply and potentially higher costs are important issues for the region's energy-intensive industries—aluminum, in particular—which consume large amounts of power, but at reduced rates, and provide economic stability in the form of jobs. Second, the dams necessary for the hydroelectric plants threaten the well-being of the salmon populations because they prevent or hinder the movement of fish both downstream to the ocean and upstream to breed. Third, the capacity of the hydroelectric plants has reached a maximum, and hydroelectric power will not be able to support the region's projected growth and increased demand for electricity. In addition, future salmon recovery efforts such as potentially removing four dams on the lower Snake River may result in a decrease in hydroelectric generation.

This study provides insights into the macroeconomic implications of three questions:

1. How can the Pacific Northwest ensure a steady supply of affordable power to meet growing regional demand?
2. How could the region replace the power that would be lost if the four lower Snake River dams were removed?

¹In this report, we note the differences between *installed capacity*, or *capacity*, typically calculated in megawatts (MW); *firm energy*, calculated in average megawatts (aMW); and *energy*, typically calculated in megawatt-hours (MWh).

3. How could the region generate the additional power that will be needed by a growing population regardless of the status of hydroelectric production?

The business-as-usual expectation is that future demands will be met by power plants fired by natural gas. Alternatively, the region could diversify its energy portfolio, i.e., it could rely on energy sources and end-use technologies that carry varying risks, like those already in the portfolio. For example, demand growth could be slowed by implementing energy-efficiency measures, and the power supply could be bolstered by renewable-energy sources such as solar and wind power. (Additional renewable-generation options such as biomass-fired generation and geothermal power were beyond the scope of this study, as were such fossil-fuel alternatives as advanced coal technologies.)

In addition to the macroeconomic implications of replacing future fossil-fueled generation with renewable generation and energy efficiency, this report discusses effects on the production of pollutants from power generation.

Each choice requires tradeoffs. For example, the power generated by natural-gas-fired plants, while relatively cheap compared to that produced by other fossil fuels, is more expensive than the hydroelectric-dominated mix the Northwest presently uses. Energy-intensive industries may bear the burden of increased costs, which could adversely affect the region's economy. And while natural gas is cleaner than some fossil fuels, it does create emissions, particularly carbon dioxide (CO₂), which have not heretofore been a major byproduct of electricity production in the Northwest. Hydropower is subject to significant availability swings and has a negative effect on salmon populations, while wind and solar power are both relatively expensive to build, yet they have no fuel costs. Finally, some energy-efficiency measures are cost-effective, but their impacts can be uncertain.

Finding Solutions

All potential energy-generation mixes have advantages and disadvantages, and decisionmakers must understand the tradeoffs and be able to assess the economic and environmental impacts of different portfolios.

This report explores the macroeconomic implications of different electricity-generation mixes for the Pacific Northwest economy. EIA forecasts of future generation growth were used to develop the following options:

- Diversify the current mix by replacing 20 percent of the projected growth in natural-gas combined-cycle generation with

- Wind turbines,
- Increased energy efficiency, or
- Combinations of wind power, solar power, and energy efficiency.
- Provide two options for the energy-intensive direct-service industries (DSIs) that purchase electric power directly from the Bonneville Power Administration (BPA) and other suppliers of bulk electric power:
 - Invest in enough energy efficiency to cover their demands or
 - Have DSIs pay market rates for power.
- Remove the four lower Snake River dams and replace their power capacity with
 - Natural-gas combined-cycle generation,
 - Increased energy efficiency, or
 - Combinations of wind power, solar power, and energy efficiency.

Key Assumptions

The analysis required several assumptions, which are discussed in more detail in Appendix A. They include:

- The future costs of alternative technologies and of natural gas.
- The numerous assumptions embedded in the Policy Insight Model developed by Regional Economic Models, Inc. (REMI), which we used to perform this analysis.
- The status of the technologies for energy efficiency and solar and wind power, along with their availability in the Northwest. For example, solar panels are not currently produced in the region but are imported into it. Introducing production in the region could have positive economic impacts.
- The period of analysis. A 20-year period was used to assess all project impacts. The base year was fiscal year 1998, but the period of analysis extends from the implementation year (2005).

Summary of the Analytical Results

The technology mixes were developed to present a broad range of options, but we have not attempted to assess whether the outcomes are achievable or how they could be achieved. The options we consider are not necessarily those that will be easily achieved, although care was exercised in picking plausible options. For example, we have not considered the implications of replacing future power generation with such renewable technologies as geothermal and biomass

generation because their costs (and presumably their macroeconomic implications) would fall roughly between those of wind generation and solar generation. The results thus bound the problem with the low- and high-end economic implications of renewable technologies. Similarly, the ability to produce the amounts of renewable generation in the options examined is contingent on the availability of that much generation in the region to be developed. In all cases, the options contain considerably less generation than could technically be developed.

Moving the markets and technologies and achieving the mixes considered will require policy changes and will perhaps involve some additional costs. Detailing these options is beyond the scope of this project, given the assumptions that had to be made and the macro level of the modeling. However, the model estimates provide useful indications of whether changes in future expectations can have an impact on the economy, and the results show that reasonable changes in the mix can be made with no significant long-term macroeconomic impacts on the region.

Key results from the analysis include the following:

- The Pacific Northwest could shift some of its energy portfolio toward renewable-energy generation without harming the economy.
- Replacing some of the future natural-gas generation would have positive environmental benefits.
- There are potential immediate benefits of introducing energy efficiency in the short term; a diverse generation mix could then be phased in over time.
- There are innovative approaches to working with the demands the DSIs put on the system. Investing in energy efficiency to match the demand required by the industries could have a positive impact on economic growth.
- The four dams on the lower Snake River could be removed without negative consequences to economic growth and net employment.

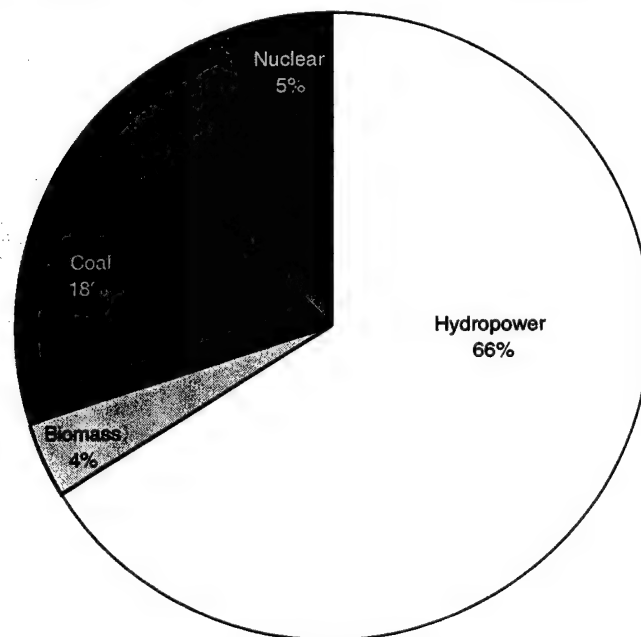
The quantitative analysis does not consider all the benefits that might be achieved from having a more diverse mix of resources; for instance, it does not address the implications of reductions in pollution or the increase in the distributed nature of the system. Nevertheless, these actions could provide substantial benefits. Additionally, it is not certain that all of the costs have been captured, although a conservative approach was used to capture most of those that could be associated with shifts to different technologies.

Organization of the Report

Section 2 provides additional background information that might be helpful in understanding the current energy environment in the Pacific Northwest. Section 3 describes the methodology used in the analysis, and Section 4 discusses the results as they relate to each of the alternative strategies and their potential for the future. Appendix A provides the details about the methodology of the study, and Appendixes B and C present excerpts from two studies from which we extracted most of the cost data used in the macroeconomic modeling. The first is a study of removal of the lower Snake River dams, and the second is an analysis of the effect on the economy of deploying renewable technologies in two regions in the United States.

2. Background

Much of the Northwest's hydropower is generated by hydroelectric projects owned and operated by the Bureau of Reclamation and the U.S. Army Corps of Engineers through the Federal Columbia River Power System (FCRPS). There are 55 major hydroelectric projects on the Columbia and lower Snake rivers and their tributaries. Twenty-nine of the 55 dams are federal, and 26 are nonfederal. The BPA markets and distributes the power generated from the federal dams at cost-based rates, which are some of the lowest in the nation. In fact, the BPA supplies 40 to 45 percent of the electricity used in the Northwest, more than 80 percent of which is hydroelectric power. Revenues collected through power rates cover the cost of operating and maintaining these projects and contribute to the region's efforts to protect and rebuild fish and wildlife populations in the Columbia River basin. The Northwest exports hydroelectric power in the summer, but it also imports electricity in the winter; therefore, the appropriate indicator of energy use in the Pacific Northwest is the mix of firm-energy resources (Figure 2.1). Most of the imported electricity is generated by a mix of coal- and natural-gas-fired plants in neighboring states, so the Pacific Northwest



SOURCE: Northwest Power Planning Council (NWPPC), 1998.

Figure 2.1—Mix of Firm-Energy Resources in the Pacific Northwest in 1996

has a higher percentage of those resources in its firm-power mix than it has in its installed-capacity mix.

Implications of Dependence on Hydroelectric Power

The Northwest's dependence on hydroelectric power creates some potential problems. First, the supply of hydroelectricity is highly variable. The amount generated in any one year depends on the amount of rainfall in the region. Twenty percent swings in energy generation between wet and dry years are not unheard of. From a business standpoint, this uncertainty presents concerns because it affects costs. In low water years, costs are higher; in wet years, costs may be lower. During a dry season or an uncommonly dry year, the levels in dams can be so low that power loads need to be significantly curtailed. This happened in the winter and summer of 2000. Typically, in the summer, the Pacific Northwest runs an excess of power, which it sends to California, where a deficit is experienced at that time. During the summer of 2000, the Federal Energy Regulatory Commission (FERC) ordered the BPA to supply additional power to California above and beyond the surplus, drawing down the reservoirs in advance of the normal schedules. Precipitation in the Pacific Northwest was below normal levels, and this sharp reduction in hydroelectricity output was an important contributor to the West Coast energy crisis of 2000–2001.

Second, while dams are not the only threat to the well-being of native fish populations, dam construction inhibits the ability of anadromous fish¹ to travel upstream to spawn and creates barriers to juvenile fish migrating downstream as they begin their biological changes for living in salt water. The result has been a steady decrease in wild salmon populations since multiple dams were built. On the Snake River, for example, since 1960—before the four lower Snake River dams were constructed—the number of salmon making the journey upstream has fallen 90 percent. Seventy-one percent of the area of Washington and 50 percent of Oregon contain watersheds with salmon and related species listed as threatened or endangered.

The Army Corps of Engineers conducted a feasibility study of ways to improve the migration of young salmon through the four dams it operates on the lower Snake River.² The ideas studied included breaching or removing the dams to recreate a natural river. This option presents a number of concerns, however, including the loss of the power the dams provide to the system. Our analysis

¹Fish that ascend rivers from the sea for breeding.

²See U.S. Army Corps of Engineers, 1999.

also considered the impact of removing the dams on the economy and employment.

Third, the energy-intensive industries (primarily aluminum) that consume a significant amount of power in the Northwest and rely on long-term, low-cost contracts purchased directly from the BPA are greatly impacted by the allocation of cost-based federal hydroelectric power.³ In 2000, during the electricity shortage, DSI customers shut down and resold power at higher rates, pursuant to agreements with the BPA; they continued to pay their employees, and they made profits without producing product. There are pressures to have these companies either pay market rates or reduce their load on the system. A few options for developing an energy portfolio to hedge against having these industries shut down again are considered in this analysis.

Projections for the Future

Current projections show that, in the future, the majority of all new electricity generation in the Northwest—in fact, in the entire West—will come from natural-gas-fired plants. In the Western region as a whole, 8,600 MW of natural-gas-powered generation has either recently come online or is coming online soon, 10,000 MW has been approved, and an additional 15,000 MW is under review. Figure 2.2 shows the relative importance of each generation technology for 1999, and Figure 2.3 shows the EIA forecast for 2020.⁴ The major change in this period is the large increase in natural-gas combined-cycle capacity, which grows from a little less than 2,000 MW in 1999 to more than 16,000 MW by 2020.

All of the other technologies maintain approximately the same share of the total installed-capacity mix. In the EIA forecasts, wind, solar photovoltaic, solar thermal, biomass, and other non-hydroelectric renewable-resource capacities constitute less than 1 percent of the generation mix and are not shown in the figures.

The use of natural gas as a power fuel is projected to grow because the technologies used for burning it are efficient and provide flexibility in the

³These industries have recently received a partial renewal of those contracts for an additional five years, from 2001 to 2006.

⁴These data are for the four-state Pacific Northwest region (Washington, Oregon, Idaho, and Montana). Data from the EIA *Annual Energy Outlook 2002* projecting installed capacity for the Northwest Power Pool (NWPP) area (which comprises Oregon, Washington, Idaho, Montana, Nevada, Utah, and Wyoming) were used to estimate installed capacities for the four states from state-level data on currently installed capacity.

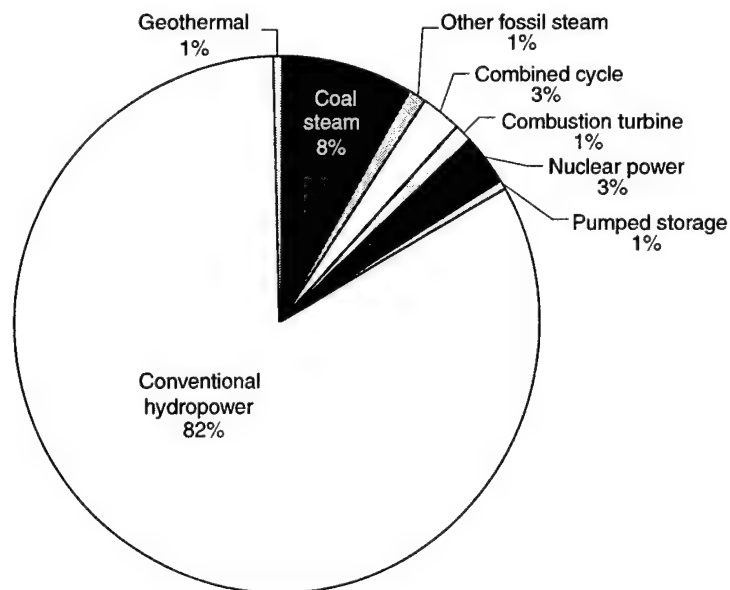


Figure 2.2—Installed Capacity of Power Technologies in the Pacific Northwest Region in 1999 (EIA Data)

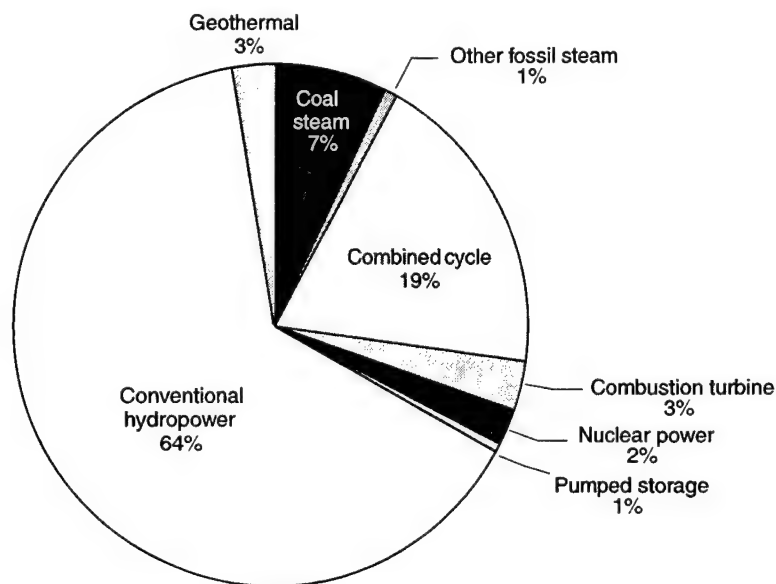


Figure 2.3—Installed Capacity of Power Technologies in the Pacific Northwest Region in 2020 (EIA Projection)

electricity mix. Some increase in gas use is warranted in the Pacific Northwest region; however, increased reliance on natural gas will increase the need for sufficient supplies at a reasonable price, thus introducing a different type of uncertainty. More than 80 percent of the natural gas currently used in the region is imported. The implications for market prices and transmission constraints as

the need grows are not well understood; however, it is likely that prices will increase, and other analysts have noted the downside potential of a heavy dependence on natural gas.⁵ The EIA presents different scenarios for its price forecasts, and the 2020 "pessimistic" forecast is 50 percent higher than the base forecast. These forecasts depend on numerous assumptions, including expansion of the gas pipeline to increase capacity. If current expectations are not met, there would be significant pressure on prices to go even higher than forecast.

Another potential problem with natural gas is that while it is cleaner than other fossil fuels, it still produces emissions, particularly CO₂. Because the Northwest has relied for so long on hydroelectric power to meet its energy needs and hydroelectricity is relatively clean from an emissions standpoint, air pollution has not been a major concern. However, as more fossil fuels are burned, emissions will increase, and this will create concerns about the effect of the generating plants on local air quality as well as their contribution to the greenhouse effect, especially in view of mounting concern over global climate change.

Overview of Energy Efficiency, Wind Power, and Solar Power

Energy Efficiency

Energy efficiency can mean three things: producing the same level of service using less energy, getting more service out of the same input of energy, or a combination of the two. For example, in the residential sector, if a home appliance is replaced with one that is more energy-efficient, the same level of service may be achieved using less energy. A different appliance might provide a superior level of service using the same amount of energy. In each case, less energy is used per unit of output.

Measuring energy efficiency and using the results to evaluate the contribution of energy efficiency to the energy portfolio is more complicated, however. In the first example above, the reduction in energy use can be measured directly, but in the second example, the superior level of service—the change in utility or comfort, for example—eludes succinct definition. A definition proposed by the EIA states that "increases in energy efficiency take place when either energy inputs are reduced for a given level of service or there are increased or enhanced services for a given amount of energy inputs" (EIA, 1995). One indicator of

⁵See, for example, Washington State Office of Trade and Economic Development, 2001.

aggregate energy efficiency for the Pacific Northwest region is energy used per gross regional product, but this rough measure does not consider structural changes in the market. For instance, changes in the industrial mix of the region to less energy-intensive industries will change the aggregate energy intensity; however, this may not be considered energy efficiency per se.

Figure 2.4 shows energy intensity measured as energy use per gross state product of industry for the industrial sectors in Washington, Oregon, Idaho, and Montana from 1977 to 1997. With the exception of Montana, industrial energy intensity in the states declined during this period. While a shift away from energy-intensive industries may account for much of this decline, decreased energy consumption may also be the result of more efficient industrial production over the study period.

There are a variety of energy-efficiency opportunities for buildings. For homes or commercial and small businesses, energy efficiency could mean using less energy to heat, cool, and light buildings—the three largest energy-using activities. Reducing the energy consumed frees up income or revenues that can be spent on other activities.

Efficiency measures for the residential sector include more energy-efficient appliances (such as refrigerators, clothes washers and dryers, and dishwashers), improved efficiency of heating and cooling equipment, improved building-shell

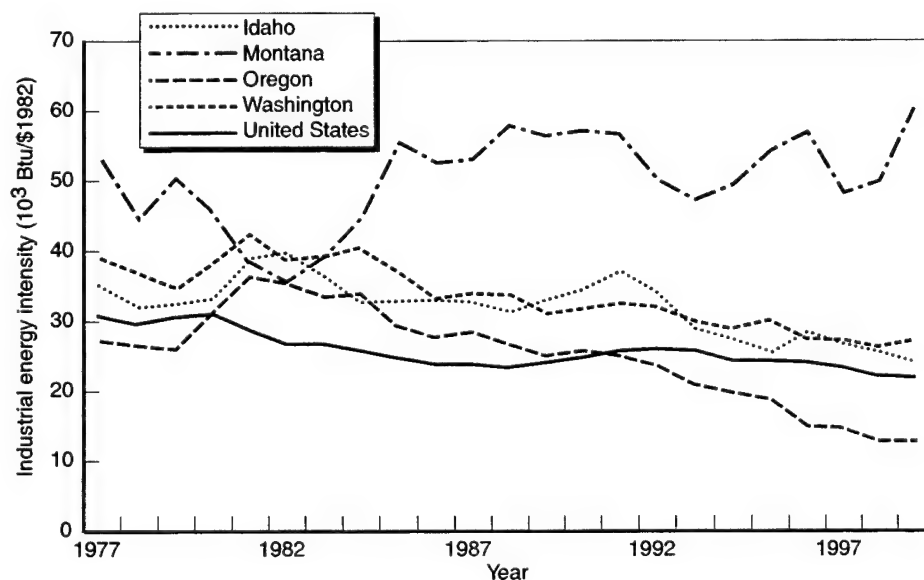


Figure 2.4—Industrial Energy Intensity in the Pacific Northwest and the United States

efficiency, and compact fluorescent lighting. Building codes increase the efficiency of new homes, so as more new homes are built, energy intensity decreases.

In the commercial sector, better heating, ventilating, and air-conditioning controls, more efficient lights, and improved insulation and windows increase energy efficiency. Again, an increase in building stock will decrease intensity, as will commercial building energy codes, just as in the residential sector.

Our analysis includes a strategy that substitutes a percentage of future electricity-generation growth with energy efficiency. Due to the limitations in the macroeconomic framework, only two scenarios of average cost of energy efficiency are used, one assuming approximately 1.5¢/kWh and one assuming approximately 3¢/kWh, with an average technology lifespan of 10 years.

Wind Power

Wind has been used as a source of power at least since it filled the sails of seafaring travelers 5,000 years ago. Windmills have been used since the early 1900s for agriculture and to pump water. In the early 1970s, increases in the cost of fossil fuels spurred new interest in wind power, and by 1997, wind energy was the fastest-growing energy technology worldwide, growing at a rate of 25 percent to a total installed capacity of almost 8,000 MW.

Like other technologies, wind power has both advantages and disadvantages. Wind is free, renewable, and clean. Wind systems can provide power to remote towns and residences that do not have traditional electricity transmission and distribution systems. Compared with other non-hydroelectric renewable technologies, wind power is cost-competitive. In fact, as a result of advancements in wind-turbine technology, wind has been able to compete in price with more-mainstream power-generation technologies. The cost of electricity from wind has dropped from 35¢/kWh in 1980 to less than 4¢/kWh in 2001 at good wind sites.

On the other hand, wind cannot be controlled or predicted with great accuracy. Wind power is therefore intermittent and needs to be considered differently from most fossil-fuel alternatives. Wind turbines also must be located at optimal wind sites, which may not be close to transmission lines. In addition to the higher cost to build these lines, transmitting the power over long distances incurs larger losses. Many of the issues of scheduling intermittent power can be overcome with large utility-sized wind farms, however, and the Pacific Northwest may be well suited to adding a large amount of wind generation because of the

flexibility of the hydroelectric system in shaping available energy to meet firm demand.

Growth of wind-powered energy generation slowed during the latter part of the 1990s because of low prices for wholesale power, coupled with uncertainties about deregulation and competition in the electric power industry. Nevertheless, the U.S. wind industry currently generates about 3.5 billion kWh of electricity each year, which is enough to meet the annual electricity needs of 1 million people. From 1998 to 2000, installed wind capacity grew from almost 1,900 MW to more than 2,500 MW. In 2001 alone, nearly 1,700 MW of wind-generation capacity was installed in the United States.⁶ Wind technology is considered mature, although it will benefit from additional economies of scale.

Hybrid systems, which include additional generating systems such as solar power, can provide improved reliability in times of low wind generation. Large utility-sized wind farms are the most cost-effective means of using wind generation, since they benefit from economies of scale.

FPL Energy, LLC, has erected the second-largest single wind farm in the world on the border between Oregon and Washington. The Stateline Wind Project contains 399 wind turbines with a combined output of about 263 MW. PacifiCorp Power Marketing has purchased the entire output of these turbines to hedge against price volatility in the West.⁷ The power is being moved through BPA and PacifiCorp transmission lines. The BPA and other utilities plan to supply hydroelectric-power resources and associated services to "shape" the variable wind energy to create a more reliable and load-matched product for sale to customers.

Solar Power

Simply put, solar photovoltaic technology harnesses solar radiation to create electricity. The technology to achieve this has been in development since the 1960s but has only recently begun to gain market share. Currently, solar power supplies less than 1 percent of the electricity in the United States.

Solar power has several advantages. Because it must be generated during the day, it may coincide with the normal peak demand of customers. Photovoltaic energy does not pollute the environment during generation. It can be controlled

⁶According to the American Wind Energy Association (www.awea.org). See the news clip at <http://www.awea.org/news/news020319glo.html> for further information.

⁷See www.statelinewind.com for more information.

by the customer and may be located near where it is used and where energy is most limited and most expensive. It can possibly delay investments in distribution and transmission systems by the utility companies. Because it is powered by a free, renewable, and abundant power supply, solar electricity helps to mitigate the risk of fossil-fuel price volatility and can improve grid reliability, thus providing a strategic contribution to an energy portfolio.

Where access to power transmission lines is possible, solar power can be connected to the power grid. In these cases, the solar power supplied to businesses and residential customers can be supplemented by power from the grid. Connections to the grid also allow consumers to take advantage of net metering laws in Montana, Oregon, and Washington.⁸

On the other hand, solar power, like wind, is intermittent and not easily predictable on a day-to-day basis. In addition, the price of solar electricity is not competitive with bulk, base-load power; prices for solar power are in the range of \$5/W for large installations. However, the high costs of solar power are expected to decrease in both the near and far term.⁹ The technology is still considered new and will enjoy the benefits of increased learning as production rates increase and manufacturing inefficiencies are worked out.

In our analysis, we used a few different linear improvement rates of the technology, from a 20 percent decline in price between 2004 and 2020 to a 60 percent decline. In the scenarios developed here, the assumption for solar (and wind) power is that the utilities and power producers need to sell "firm" power. This means that to sell 1 MW of average power, it is necessary to construct about 4 MW of peak capacity (see the Appendixes for further information on availability rates of these technologies). This is a conservative assumption because it essentially quadruples the costs of the renewable technologies, but in the actual market, these technologies might not sell "firm" power. For example, solar-power producers would most likely sell power at peak times during the middle of the day when the output is in general more predictable. The utilities may need to supply some backup capacity, but not three or four to one. In addition, solar technologies would likely substitute for peak-load generation, which is more costly and more polluting than gas-fired combined-cycle base-load generation.

⁸Net metering entails sending excess power generated onsite into the electrical grid. A meter at the site of the power generator monitors the net difference between power input to the grid and power used from the grid and charges consumers for only the power they take from the grid, net of the power generated onsite.

⁹See Kydes, 1999.

3. Methodology

Defining Options in Terms of Alternative Energy Portfolios

The electricity environment in the Northwest is analogous to a financial portfolio. Some recent studies¹ use aspects of portfolio theory to show that increasing the diversity of the electricity mix, in particular adding the use of renewable-energy sources, can reduce risk and improve the expected benefits from electricity. This concept provides some insights into the analysis and the tradeoffs associated with each of the choices for the future.

The portfolio contains assets that have different risks and returns. These vary across time, some returning short-term benefits, and others, long-term benefits. Energy-related policies and alternative technologies serve as options to hedge against risk and uncertainty. Diversification of the portfolio can yield an "efficient set" of energy and environmental assets that have lower risk and higher returns than any one asset has alone. The levels of risk and returns are relative to goals to be achieved from the portfolio. These might include economic growth, employment, lower emissions or environmental impacts, and productivity, among others. For the Northwest, the near-term goal could be supplying low-cost power with minimal risk and minimal impact on the environment.

Some portfolios maximize the expected economic value of the power system at some defined level of risk; conversely, some portfolios minimize risk at some defined level of economic value. Balancing the interplay of risk and value is beyond the scope of this project, but the analysis should help us understand the importance of the drivers.

The performance of the portfolio might be measured by the effects of changes in energy costs and availability of energy on the economy. Another portfolio measure might be the effects of the mix of energy sources on the diversity and vulnerability of the supply. These measures reflect the uncertainties and risks of the underlying assets. As mentioned above, hydroelectric power and natural gas both entail certain risks—the volatility associated with price (in the case of gas)

¹See, for example, Awerbuch, 1996; Awerbuch et al., 1996.

and availability (in the case of hydroelectric power). Each of these risks affects the expected return of the asset. In contrast, certain renewable-energy sources, such as solar and wind power, have capital risks (they are more expensive to implement) and uncertain capacity-peaking benefits, but their longer-term costs and availability are fixed and predictable. Therefore, they can provide higher value to the portfolio with respect to the risk value, even though they have higher capital costs.

In the present study, the portfolio value is defined as the change in economic growth and net employment. Alternative options are compared to the "status quo" portfolio, which assumes that all new demands are met through natural-gas combined-cycle generation.

Another important value of the portfolio might be the ways the energy sources affect the environment. There are benefits to reducing air pollution, from reductions in health-related costs to reductions in impacts on the built environment from acid rain, to name only two. These are difficult to quantify and are not measured in this analysis, but the amount of potential reductions is discussed.

Estimating Economic Impacts

To estimate the economic effects of alternative energy policies, the project team used the well-documented REMI Policy Insight Model,² an economic and demographic forecasting and simulation model with elements of econometric, input-output, and computable general-equilibrium (CGE) models. The model is explained in more detail in Appendix A. The version used in this study models 53 economic sectors (49 private and four government sectors) in the Pacific Northwest region, which comprises Idaho, Montana, Oregon, and Washington.

Our work with the model can be generalized to three steps: collection of economic impact data, data preparation and input, and interpretation of results.

Data Collection

Collecting the appropriate data for the REMI model requires identification of the direct economic impacts of each energy-use scenario. These impacts can be categorized into several general types:

²See Treyz, 1993.

- Changes in energy rates (prices for electricity, natural gas, and fuel oil) for different classes of consumers (residential, commercial, and industrial).
- Changes in demand for various sources of energy (electricity, natural gas, and fuel oil) used by different classes of consumers.
- Changes in the mix of available energy sources to consumers.
- Changes in demand for specific goods and services from specific economic sectors by both energy producers and consumers.

Data Preparation and Input

Once the data are aggregated, the impacts are assigned to appropriate REMI policy variables. (The policy variables used for each scenario are described in Appendix A.)

To assess the impacts of different choices in technologies, we changed the mix of technologies projected to 2020 from that projected by the EIA to a mix containing more renewable-energy technologies and energy efficiency. In our scenarios, 20 percent of *new* natural-gas combined-cycle generation each year is replaced with either increased efficiency, solar or wind power, or a combination of these. For example, in the scenario where wind power is the only replacement technology, 20 percent of *future* installations of combined-cycle generation in each year are replaced with wind generation.³ Our choice of wind turbines and solar photovoltaic generation as renewable-energy sources is illustrative, in that the costs of wind power tend to be on the low side, whereas those of solar photovoltaic generation tend to be on the high side. This is not to say that these are always the highest- and lowest-cost technologies available in an area. For instance, the Pacific Northwest has an abundance of potential biomass-fueled generation and geothermal electricity production, the latter of which is projected to grow by a factor of six over the next 20 years.⁴ Including these as renewable options was beyond the scope of this study, but it should be noted that wind and solar are not the only renewable-power-generation technologies.

In some of our scenarios, the power generated by the four lower Snake River dams was replaced with different combinations of natural-gas combined-cycle generation, energy efficiency, and wind power. We included costs of removing the dams over a period of two years and of building the replacement power

³We assume approximately 14,000 MW of new capacity in the regions; therefore, by 2020, we replace 2,800 MW of gas-generated power with enough wind power to cover the expected generation from the gas-fired plants. This is approximately 8,000 MW of installed capacity.

⁴See footnote 4 of Section 2.

generation over the same period. The effects of increasing energy efficiency to replace the power consumed by the DSIs were also estimated. The amount of generation was estimated, and overnight (i.e., in a single year of the analysis) costs of installing the replacement power were incurred.

Output from the model includes the effects of changing the investments in each technology on the regional economy and net employment. First, investments in a business-as-usual strategy were determined. Then changes in investments that would occur if the combined-cycle generation were replaced with other technologies were estimated. These different investment strategies affect the cost of electricity. The changes in investments and costs in the regional sectors were then input into the REMI model.

Interpretation of Results

Once the data were assigned to the appropriate policy variables, the REMI model was run. The results were produced at the same level of aggregation as the inputs and were then disaggregated using the same Department of Commerce databases that were used to aggregate the input data. Forecasts are reported for changes in employment, industry output, and industry value-added. When the value-added contributions for all the industries in a region are summed, the result is known as the gross regional product. The results presented in this analysis are change in gross state product from the base case and change in net employment (job-years) from the base case. This type of model is useful because it allows for tracking flows in the economy and assesses the implications of changing mixes on industrial sectors as well as on energy consumers.

Many assumptions go into the model. One assumption is that input-output analysis is static, and while REMI has some dynamic elements built in, the basic technological mix in the industrial sectors stays fixed. This is not a problem for short-term analysis, but over the long term, it can have impacts. It is important to note that these impacts are small economic changes. Other assumptions include the costs of technologies and the industries that produce components for those technologies (the input data are presented in Appendix A). Clearly, the results will be affected by assumptions of technology cost and efficiency. To better understand the impacts of these costs, we have used two cases of technology innovation—a base-technology case and an advanced-technology case. For the most part, changes in the results for the different technology assumptions are small.

4. Findings from the Analysis

This section reviews the results of the different options and discusses the impacts of different assumptions on those options. We begin with an examination of the options for replacing future gas generation; we then address the implications of different scenarios for the DSIs; finally, we look at the impacts of removing the lower Snake River dams. The impacts of all of the alternative options, either positive or negative, on the regional economy are very small, in most cases less than one-half of 1 percent of the gross regional product. Given the uncertainty in the assumptions and the model, it is difficult to say that any of the results are distinct from having no impact on the economy. Because of errors associated with the model and the data, the small perturbations in the economy are not statistically or analytically significant.

The results of the analysis depend on the structure of the economy in the Northwest and how it is reflected in the model. The gas and electric sectors have a larger impact on the Northwest regional economy than they have on the nation as a whole, so a reduction in demand for gas and electricity has a relatively large negative effect.

Diversifying the Portfolio with Energy Efficiency and Renewable Generation

As previously noted, expectations are that, absent policy incentives and significant price changes, most new power generation in the Northwest will be natural-gas combined-cycle generation. This means that almost 90 percent of the portfolio will continue to be based on hydroelectricity and natural-gas-fired generation. The mix is thus exposed to both weather-related and natural-gas-price-related uncertainties. What are the consequences of adding more renewable generation and energy efficiency to the mix? We include efficiency as a "supply-side" option, since the investments can be made as if they are supplying an equivalent amount of generation. As previously noted, we examine the implications of replacing 20 percent of future generation with efficiency, and we examine the impacts separately and together. We also look at the implications of rising gas prices and improved technologies. For each of the strategies, we start with the assumption that gas prices remain at \$3/mcf (million

cubic feet) through 2020.¹ We then examine the impacts of different gas-price paths, including having the price rise to \$6/mcf by 2020, and also having it rise to \$6/mcf by 2010 and remain steady thereafter. We also examine the impacts of changing technologies, including the impacts of learning effects, which bring down the costs of all the technologies.

Figures 4.1 through 4.9 show a range of impacts for each of the technology mixes. The lower bound is the impact when gas prices are at \$3/mcf and the base-technology costs are as described in Appendix A. The upper bound reflects reduced technology costs for renewable generation, 1.5¢/kWh for energy efficiency, and \$6/mcf for natural gas by 2010. All other combinations of technology development and natural-gas prices fall between these bounds. Therefore, we use these two limits as upper and lower bounds. The shading represents the range of other possible futures that fall between them.

Figure 4.1 shows the impact on gross regional product in the Pacific Northwest region for three cases: replacing 20 percent of future installed capacity with (1) wind power, (2) wind power and energy efficiency, and (3) wind power, energy efficiency, and solar power. Table 4.1 summarizes the capacity installed in 2020 in each of these three cases.

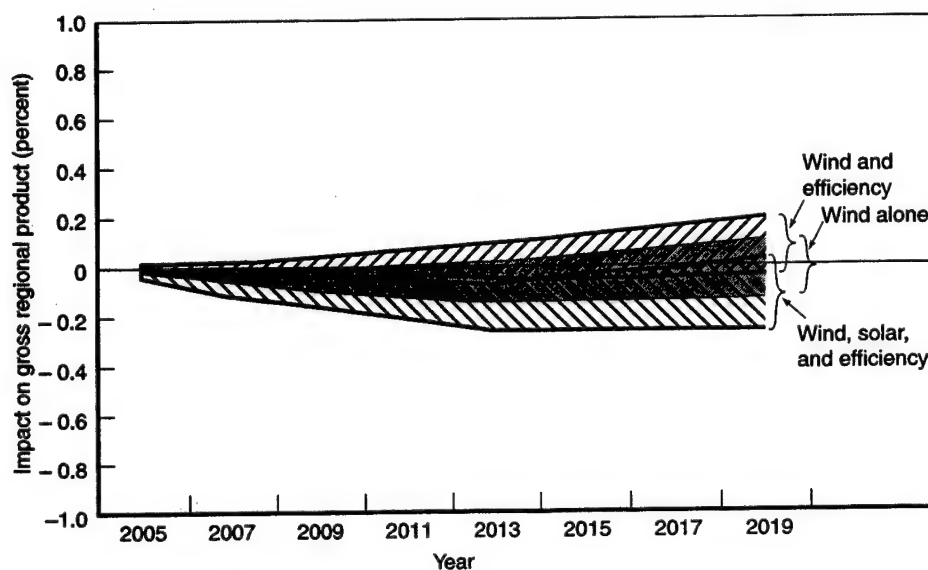


Figure 4.1—Economic Impact of Replacing 20 Percent of Future Combined-Cycle Generation with Renewable Energy and Efficiency

¹Gas prices throughout this report are in real terms (year 2000 dollars).

Table 4.1
Projections of Capacity in 2020 from Different Mixes of Power Generation (MW)

Power Source Replacing 20 Percent of Future Combined-Cycle Generation	Combined Cycle	Solar Power	Wind Power	Energy Efficiency
Wind power	8,170	116	5,470	0
Wind and energy efficiency	8,170	116	2,800	669
Wind, energy efficiency, and solar generation	8,170	1,010	2,260	535
EIA projection ^a	9,950	116	123	NA

^aTaken from projections of the NWPP that were scaled for the four states in the study, based on state-level data provided by the EIA.

At the lower bound of the “wind alone” case in Figure 4.1, the economy grows a little slower than it does in the base case, but the difference is small (less than two-tenths of 1 percent). At the upper bound, the economy grows slightly faster than it does in the base case. When energy efficiency is added to the mix (the “wind and efficiency” case), the economy grows a little faster because the cost of energy efficiency is lower than that of wind power. Adding solar power reduces the growth in the economy, because solar power is more expensive. None of the scenarios shows large changes from the base case, and none of them can be construed as significantly different from no change from the base case.

Explaining the impacts of these technology mixes on the economy is complicated. The first impact is the reduction in natural-gas and electricity use and the reduction in revenues from the companies that sell gas and electricity in the region. Significant amounts of natural-gas combined-cycle generation are being displaced, and this has a negative impact on economic growth. At the same time, imports of natural gas are reduced, which has some positive impact on growth. Adding wind power to the mix makes the electricity price slightly more expensive, which then has another negative impact, but because some of the wind-power-generating components are made in the Northwest, there is some positive rebound. It is not possible to disaggregate the magnitude of each of these effects.

When future combined-cycle generation is replaced with energy efficiency, the use of gas and revenues by the utilities is reduced, and in addition, investments are made in efficiency-related equipment. Expenditures by industries and consumers are also reduced, which may have a positive impact on industry. Moreover, consumers spend those savings, which also produces a positive economic impact.

As noted above, when solar power is added to the mix, economic growth generally slows, because solar power is more expensive than the other alternatives. For example, the model uses a 1998 base in which no solar systems are produced in the Northwest, so these systems must be imported to the region. Even so, the upper bound of the mix that includes solar power does become positive at the end of the study period.

Renewable technologies are expected to improve rapidly as more of them are deployed. As manufacturers and users gain experience with the technologies and sell more products, the costs per unit should decline. For example, in the case of solar cells, significant economies of scale may be gained in the manufacturing process. This can sharply reduce the costs of producing and installing the technology in the coming years. Such technology improvements result in only small increases in economic growth relative to the basic-technology cases. The costs of the technologies account for only a portion of the differences in the lower and upper bounds in the figures, and the outputs are not very sensitive to the relatively small changes in costs we tested. However, if natural-gas prices rise above those in the base case, the advanced technologies become more cost-competitive.

The next critical issue relates to the impact on the portfolio of rising or volatile natural-gas prices. It is possible that natural-gas prices will rise to \$6/mcf by 2020 if assumptions about gas-technology improvements and pipeline expansion are not met (EIA, 2002b). For example, the EIA's natural-gas-price forecast assumes more than 6 trillion cf/day of increased delivery capability. If this is not built in time, there will be significant upward pressure on prices. It is also possible that gas prices could rise quickly when the United States starts coming out of the recession, which could lead to a high demand for gas used in electric-power generation across the West. This is reflected in the scenario that has gas prices rising to \$6/mcf by 2010 and stabilizing thereafter. This scenario is seen in the upper limit of the range shown in the figures. Gas prices staying level at \$3/mcf and gas prices rising to \$6/mcf are only two of many possible price paths that gas may follow.

Examining the effects of the different gas-price scenarios on each option helps to elucidate the energy portfolio as a hedge against natural-gas price volatility. In the analysis, a more diverse portfolio provides positive economic growth when gas prices rise significantly. The EIA notes that including 10 or 20 percent of renewables in the U.S. electricity mix (in the form of a renewable portfolio standard) would reduce pressure on gas prices and lower the forecast price of gas by 5 to 10 percent. Therefore, the inclusion of a mix of wind power, solar power, and energy efficiency could reduce pressure on prices and provide a

positive hedge. If natural-gas prices rise higher than expected, the different mix options produce positive economic growth.

The value to the portfolio of reducing natural-gas demand that can lower fuel-price uncertainty could be approximated by the differences between the economic impacts of the scenarios—at the extreme, the difference between the upper and lower ranges. It is likely that if alternatives were introduced at the levels estimated, the reduction in new gas use would reduce pressure on prices, and we will never know if gas prices would have risen without them. Finally, the reduction in gas prices from a 10 percent renewable portfolio standard “just about offsets the higher costs of the new renewables” (EIA, 2002a, p. 19).

The effects on employment mirror those on the economy, although net employment tends to be affected more positively in the scenarios than does gross state product. Figure 4.2 shows net-employment impacts from the same sets of technologies shown in Figure 4.1. The range of net-employment impacts is plus or minus fewer than 20,000 jobs by 2020, less than one-third of 1 percent of potential jobs in the region (the expected population of persons aged 20 to 54 in the Pacific Northwest region in 2020 is almost 6 million (RAND California Databases, 2002)). Wind power alone and the wind power and efficiency mix show positive net-employment impacts, but they are all quite small, less than 10,000 jobs by 2020. Rising natural-gas prices positively affect the employment

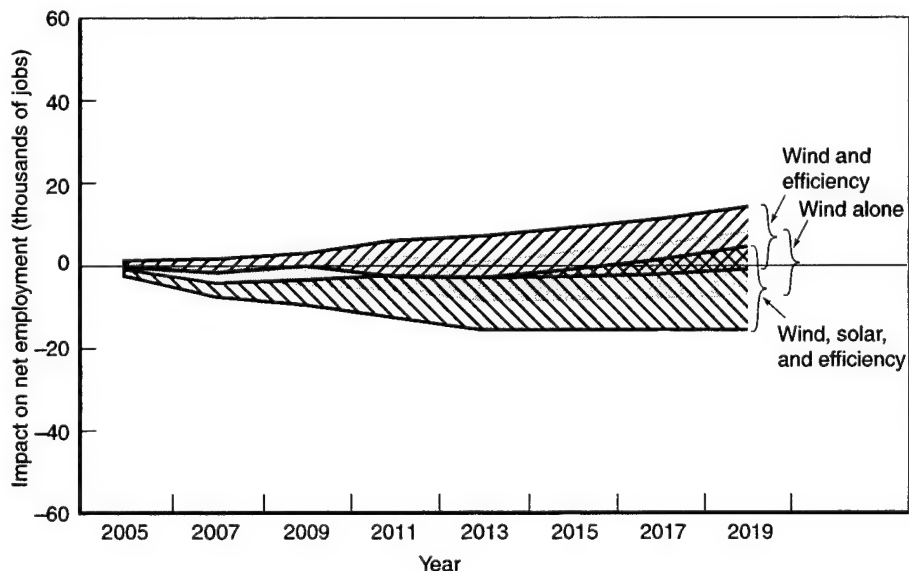


Figure 4.2—Changes in Net Employment from Replacing 20 Percent of Future Combined-Cycle Generation with Renewable Energy and Efficiency

benefits from diversifying the mix. The wind power, solar power, and efficiency option, with improved technology and gas prices of \$6/mcf by 2010, would provide positive net employment by the end of the study period.

The economy depends heavily on intermediate product and consumer imports, which have a number of impacts on the results. When energy costs are reduced through efficiency and the saved money is respent, the money does not necessarily remain within the regional economy. If the money is spent in proportion to the basic spending patterns, most of the products are imported and there is less positive impact. If patterns of consumption begin to change so that more regional products are purchased, or if more products for energy efficiency or renewable energy are produced in the region, efficiency and renewable energy will have a larger positive impact.

The Effect of Diversifying the Portfolio on Emissions

Replacing the projected natural-gas-fired generation with energy efficiency and renewable generation can have an impact on the quantity of emissions produced during power production. Figure 4.3 shows the emissions displaced by replacing 20 percent of new combined-cycle generation with renewable resources that emit no pollution.

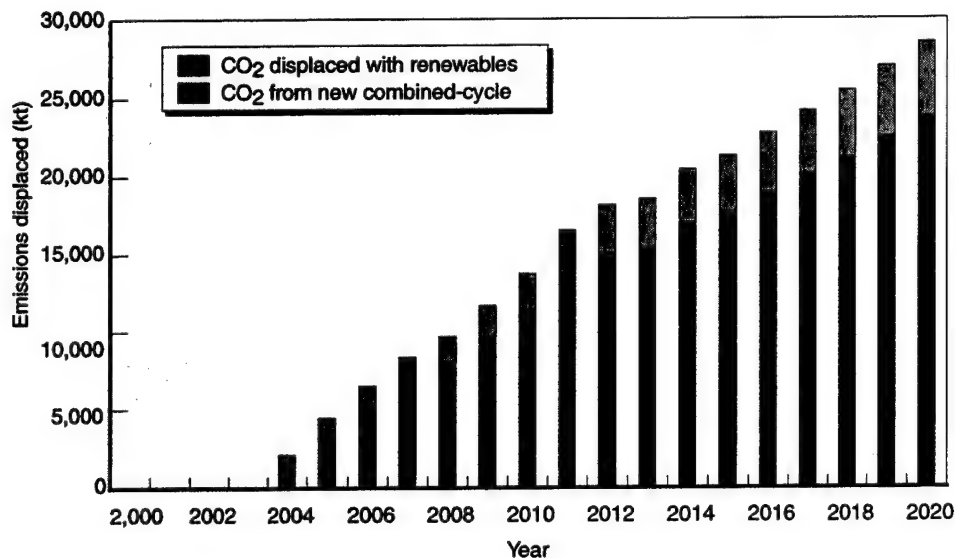


Figure 4.3—Emissions Displaced by Replacing Future Combined-Cycle Generation with Renewable-Generation Mixes

Aggregate emissions data from a natural-gas combined-cycle plant were taken from the literature.² The total emissions displaced through 2020 from replacing 20 percent of new combined-cycle generation are listed in Table 4.2.

To put these findings in perspective, we also show the total emissions in 1998 from power production in the Pacific Northwest. Because of the low emission intensity currently enjoyed in the region, the effects on the regional emissions profile from replacing future fossil-fueled generation with more renewable generation can be substantial. In the scenario where 20 percent of future combined-cycle generation is replaced with nonpolluting renewable generation, the amount of CO₂ displaced over the study period is approximately equal to the emissions from all power plants during 1998. The amounts of sulfur dioxide (SO₂) and nitrogen oxides (NO_x) displaced in the renewable-generation scenario are substantially greater than the total amounts emitted in 1998 from the fossil-fueled power plants.

Table 4.2
Effects on Emissions of Replacing Future Combined-Cycle
Generation with Renewable-Generation Mixes

Emission	Total Emissions Reduced Through 2020 by Replacing 20% of Future Combined- Cycle Generation	Total Emissions in 1998 from Power Plants in the Pacific Northwest ^a
NO _x (kg)	10,802,738	80,182
SO ₂ (kg)	227,426	112,413
CO ₂ (kt)	46,534	41,682

^aData from Environmental Protection Agency, 2000.

Meeting the Needs of the DSIs

As noted previously, there has been some debate in the Northwest about the role of the energy-intensive industries in the region—primarily aluminum smelters—that get electricity at low-cost, long-term rates from the BPA (through 2006, and perhaps longer). While these companies provide jobs and economic activity in the region, their power demands put a strain on the electricity-generation system, particularly in times of low water availability, such as the 2000–2001 period.

Two scenarios that include the DSIs are considered in this analysis. In one scenario, these industries have to pay market rates for power, which they have

²See Spath and Mann, 2000.

claimed makes them unable to be competitive. In the other scenario, a level of energy efficiency equivalent to the industries' demands is created; this would reduce pressure on the electricity-generation system and avoid the building of new gas-fired power plants in the future. In this scenario, the DSIs would continue to receive subsidized electricity.

The results of the two scenarios are presented in Figures 4.4 and 4.5. Charging the DSIs market rates appears to have no impact on economic growth or employment. The model makes some adjustments for commodity prices and the competitiveness of the industries, but it does not deal completely with the competitiveness. This suggests that higher electricity prices may not have as great an impact as the industry predicts, but not much can be inferred from these results, since simply raising prices does not appear to reduce output significantly. A potentially better option would be to generate a level of energy efficiency over time that is equivalent to the DSIs' demands. This would provide slightly more economic growth and net jobs to the region. A greater impact is seen in these scenarios than in any of the other scenarios, probably because of the relatively large amount of energy efficiency that would be installed over the years. Net employment could increase by as many as 55,000 jobs by 2020, and the economy could grow six-tenths of 1 percent faster than in the base case.

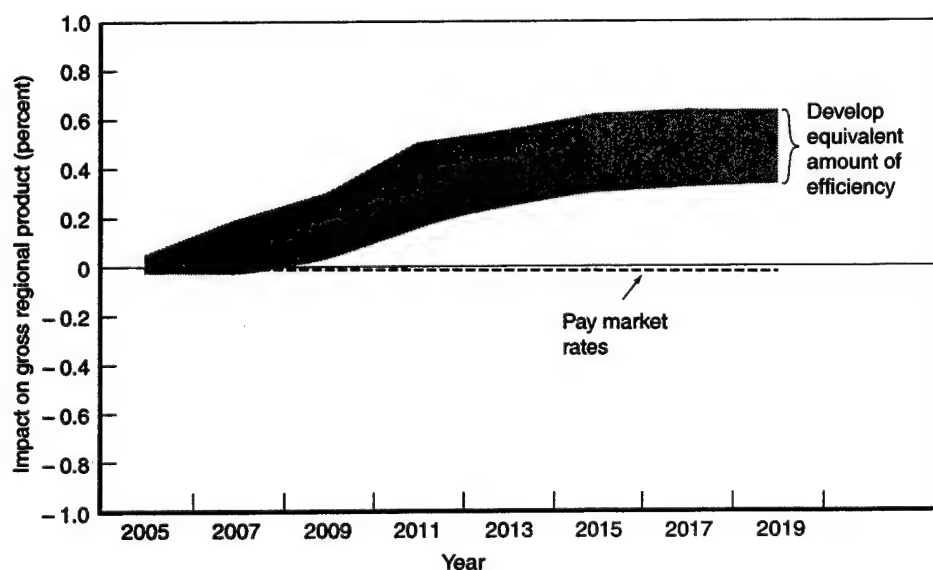


Figure 4.4—Economic Impacts of Creating an Equivalent Amount of Energy Efficiency to Replace the Power Demands of the DSIs or Having the DSIs Pay Market Rates

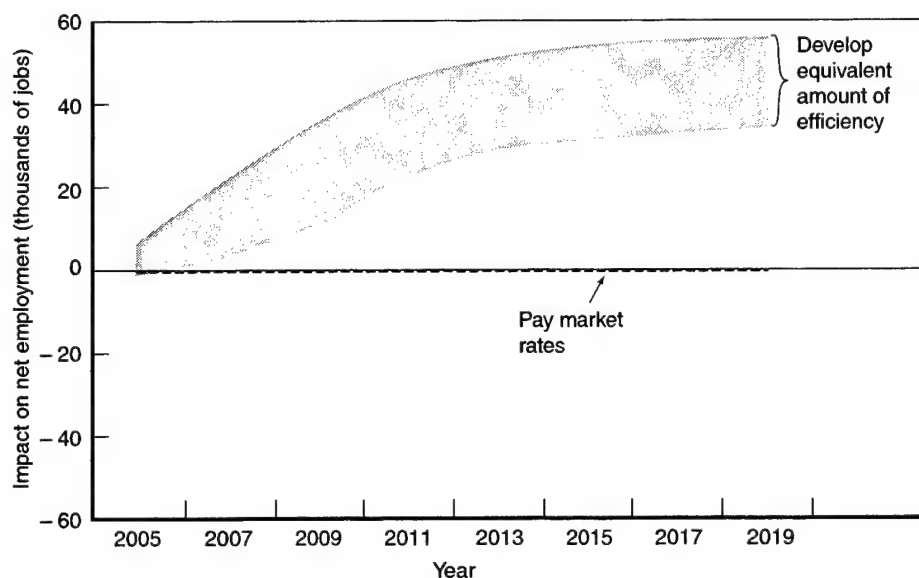


Figure 4.5—Impacts on Net Employment of Creating an Equivalent Amount of Energy Efficiency to Replace the Power Demands of the DSIs or Having the DSIs Pay Market Rates

Removing the Lower Snake River Dams

While the dams along the Columbia and Snake rivers provide cheap hydroelectric power, enable upriver navigation, and benefit agriculture, they impede the passage of salmon between the rivers where they spawn and the open ocean where they live most of their adult lives. More than \$3 billion has been spent to restore Columbia River basin salmon runs by federal taxpayers and utility ratepayers since 1980 (Mapes, 1999).

To evaluate options for mitigating the adverse impacts of the dams on salmon migration on the lower Snake River, the U.S. Army Corps of Engineers conducted a study of the four dams operating there: Lower Granite, Little Goose, Lower Monumental, and Ice Harbor. Three approaches were considered: (1) maintain the existing system with planned improvements; (2) make major system improvements to bypass facilities; and (3) use natural river drawdown (dam removal).³

³As an example, the 162-year-old Edwards Dam on the Kennebec River in Maine was removed in 1999 to reopen prime spawning habitat for 10 sea-run native species of fish. See <http://www.state.me.us/spo/edwards/>.

If the four lower Snake River dams were breached, about 1,250 aMW of hydropower would be lost in a year with average rainfall. This amounts to approximately 5 percent of the total energy produced in the regional system.⁴

Removing the dams would provide economic benefits associated with fishing, recreation, and tourism and would have a significant environmental benefit. It would also have a negative impact on some agriculture. For example, farmers currently use the Ice Harbor Reservoir to irrigate about 37,000 acres on 13 farms.⁵ Bypassing the four dams would require investments for modifications to the municipal and industrial water-use infrastructure, highway and rail infrastructure expansion, and creation of a new irrigation infrastructure. While these changes would cost taxpayer dollars, they might also create thousands of jobs, both short-term and long-term.⁶ For example, sales from recreational activities would increase by an estimated \$230 million over the next 20 years. It is more difficult to assess the environmental benefits. In this analysis, we address only the potential impacts on the regional economy.

Three options are generated for replacing the power needed by the dams, and these are compared to the base case in which the dams remain in place. In each case, estimates from previous studies of the physical costs of removing the dams were used, as were numbers on the reduction in labor and activities that currently rely on the dams (all of these costs are addressed in Appendix B).⁷ The options are to replace the 1,250 aMW with

- Natural-gas combined-cycle generation,
- Investments in energy efficiency, or
- A combination of wind power and energy efficiency.

Replacing the dams with combined-cycle generation appears to have no impact on gross regional product over the long term (Figure 4.6). There are some positive impacts before 2010, but they amount to less than one-tenth of 1 percent of the gross regional product.

If the 1,250 aMWs are made up with investments in energy efficiency, the results straddle the zero impact line. Once again, the lower bound assumes the higher cost of energy efficiency (3¢/kWh), and the upper bound assumes the lower cost (1.5¢/kWh). At the lower-cost energy efficiency, the economy grows slightly

⁴This number is an approximation compiled from a variety of sources.

⁵See U.S. Army Corps of Engineers, 1999.

⁶Ibid.

⁷It is assumed that the dams are removed by 2007 and the new generation is available by then.

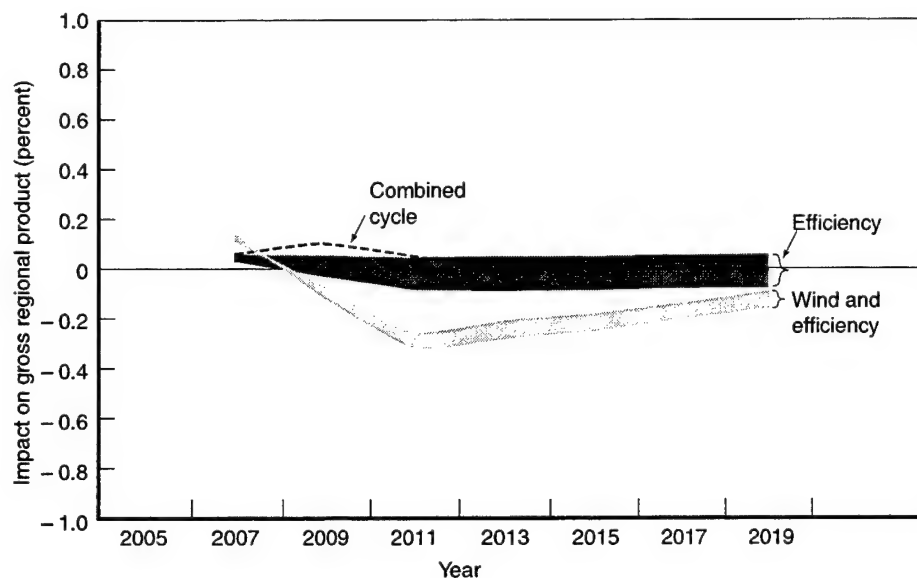


Figure 4.6—Economic Impacts of Replacing the Four Lower Snake River Dams with Combined-Cycle, Efficiency, and a Combination of Wind Power and Efficiency

faster (again, less than one-tenth of 1 percent) than it does in the base case, and it grows slightly slower at the higher-cost energy efficiency. If a mixture of wind power and efficiency replaces the dams (the lower range in Figure 4.6), the economy tends to grow more slowly, perhaps because of the large amount of capacity being replaced in a short period of time.

Net employment follows the same trend as gross regional product (Figure 4.7). Both replacing the dams with combined-cycle generation and replacing them with energy efficiency show modest positive net-employment impacts over the study period. The wind power and efficiency mix dips negative in the first part of the study period and returns to no net change by the end of the period.

When and how quickly alternative technologies are introduced and the breadth of the portfolio will make a difference in the impact on the economy. We combined a few of the scenarios developed earlier in this report to examine the impact of a combination of meeting the initial new load requirements with energy efficiency (replacing up to 3,000 MW with efficiency to cover the power used by the DSIs), removing the dams beginning in 2007 and replacing them with wind power and efficiency, and after that, meeting 20 percent of future growth with a mix of wind power and energy efficiency. This combination option is shown by the lower belt of light gray in Figure 4.8. The cross-hatched range is taken from Figure 4.6, where 20 percent of future generation is replaced

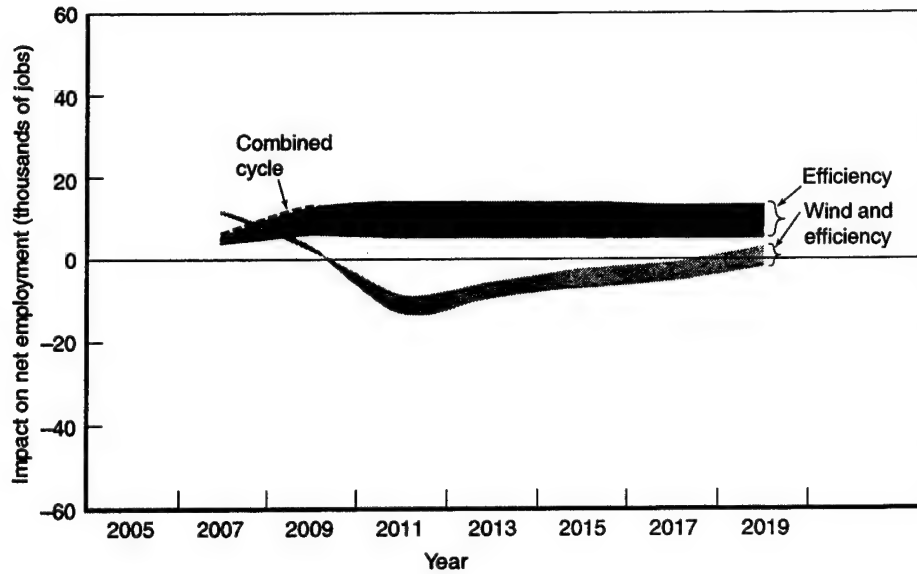


Figure 4.7—Impacts on Net Employment of Replacing the Four Lower Snake River Dams with Combined-Cycle, Efficiency, and a Combination of Wind Power and Efficiency

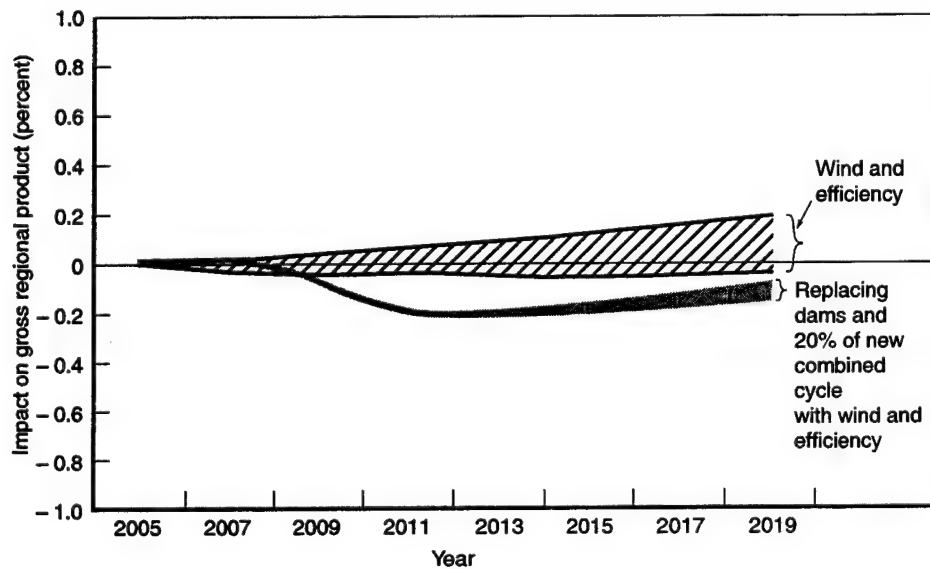


Figure 4.8—Economic Impacts of the Combination Power-Replacement Scenario or Replacing 20 Percent of Future Generation with Energy Efficiency and Wind Power

with wind power and efficiency and is shown for comparison purposes. In the combination option, the economy grows more slowly due to the extensive penetration of wind power and efficiency that results from the heavy investments to replace the power used by the DSIs and power from the four lower Snake River dams. As noted previously, simply substituting 20 percent of new generation leads to growth larger than that in the base case, while substantially increasing that number in this scenario reduces the impact. On the other hand, net employment shows positive gains through 2010, goes slightly negative, and then becomes positive again at the end of the period (Figure 4.9).

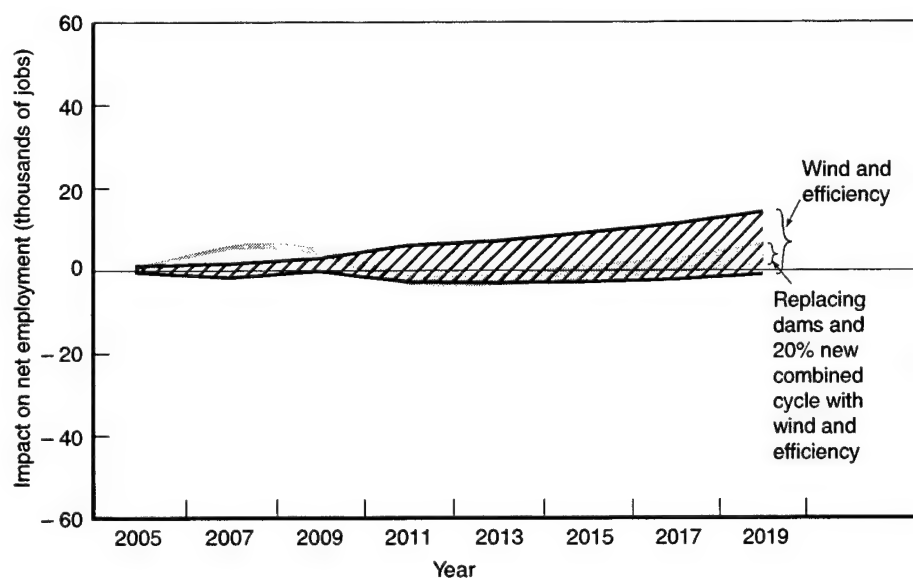


Figure 4.9—Impacts on Net Employment of the Combination Power-Replacement Scenario or Replacing 20 Percent of Future Generation with Energy Efficiency and Wind Power

5. Conclusions

The results of our analysis indicate that diversifying the energy portfolio—shifting some of the future potential natural-gas-fired combined-cycle generation to energy efficiency and some renewable options—is likely to have little impact on economic growth. Most likely, the economy will grow at the same rate whether the business-as-usual expansion occurs or 20 percent of the expansion is replaced with alternative energy sources. But hedging price uncertainty is an important policy and business factor, and a combination of efficiency measures, wind power, and solar power provides a potential reduction in fuel-price uncertainty.

Shifting away a portion of the potential natural-gas generation may also have environmental benefits. The new natural-gas-fired generation will add nearly 29,000 kt of CO₂ emissions by 2020. Replacing 20 percent of those new plants with nonemitting sources would eliminate a cumulative 47,000 kt of CO₂ by 2020. These changes would accompany reductions in SO₂ and NO_x emissions that would be felt over the entire Pacific Northwest region.

It has been shown that innovative approaches could be used to meet the demands of the DSIs on the system. Investing in energy efficiency to match the energy demand of these industries could have a positive impact on economic growth. Given that energy-efficiency investments would be cheaper for these industries than paying market rates for 20 years, one possible policy option would be for the industries to make such investments (perhaps in conjunction with the states) to achieve the reductions in energy use. In this case, states could front-load the efficiency through investments by the DSIs. The industries would maintain their electricity subsidies, but everyone would gain, because the average price of power would be lower with the introduction of a large amount of energy efficiency. The industries could still compete effectively over the long term.

Finally, our results indicate that the lower Snake River dams could be removed without hurting economic growth and employment. There would be some job dislocations, and money would have to be spent for retraining and finding new jobs for those displaced, but the regional economy would not suffer from this change.

We have not included all the benefits that might be achieved from having a more diverse mix of resources. For example, we have not addressed the increases in the distributed nature of the system or the potential restoration of fish habitats, although these might provide substantial benefits. Additionally, we are not certain that we have captured all costs, although our estimates tended to be conservative.

It is important to reiterate that while the estimates of impacts are forecasts based on the stated assumptions, the probability of these futures occurring has not been evaluated. Moving the markets and technologies and achieving these different mixes would require policy changes and would perhaps entail some additional costs. A study detailing these scenarios is beyond the scope of this project, but our estimates are useful for indicating whether changes in future expectations can have an impact on the economy. Given the assumptions that needed to be made and the macro level of the modeling, what can be judged from this analysis is that reasonable changes in the energy mix can be made without having any long-term impact on the economy.

Appendix

A. Study Methodology

The primary analytical tool used to study the economic impacts of varying the electricity-production mix of technologies in the Pacific Northwest between 2000 and 2020 was the REMI Policy Insight Model, an economic and demographic forecasting and simulation model. This model was used to evaluate a range of scenarios involving different alternatives and sources of uncertainty.

Introduction to the REMI Policy Insight Model

REMI used elements of econometric, input-output, and CGE models in formulating its structural economic model. The econometric component uses panel data for all states from the past 25 years to estimate behavioral responses of the economy to policy actions. The model was calibrated for the Pacific Northwest region, which is represented by 53 economic sectors (49 private and four government sectors). The input-output component of the model incorporates interindustry transactions among all sectors and endogenous feedback from final demand.

CGE models address the fact that changes in relative factor costs cause substitution among the factors of production—labor, capital, fuel, and intermediate demand. While REMI incorporates this substitution, it does not require all product and factor markets to clear continuously. Changes in relative costs may also affect regional profitability, taxes, and wages, and thus the location of businesses. In this study, the REMI model calculates trade flows between the Pacific Northwest and the rest of the country.

The model also contains a demographic component. Population migration occurs in response to changes in expected income, which is a function of regional employment levels, occupational mix, and wages. Local labor-market conditions such as population, labor-force participation rates, and the number of people in various occupational categories influence local wages. Wage changes affect the cost of doing business, which feeds back into the regional level of employment.

REMI has been used extensively for similar work. For instance, when the Aluminum Industry Study Group commissioned a report to look at the macroeconomic effects of the loss of the aluminum industry on the regional

economy in the Pacific Northwest,¹ REMI was used to assess the macroeconomic and energy impacts that would occur in the region if the aluminum smelters were to be closed. The impacts were statistically insignificant, on the order of four-tenths of 1 percent of the regional economy over the study period.

The regional economic implications of energy price changes were also studied using the REMI model.² A study for the Iowa Department of Natural Resources examined the effects of energy-efficiency consumer programs and utility rates on the Iowa economy. It looked at the effects on different industries of pricing and showed that the differences in value-added between industries are substantial (on the order of 1 percent) when an across-the-board rate change is implemented.

Model Structure

The REMI model consists of five components, or blocks, which interact with each other in a simultaneous way:

1. Output
2. Labor and capital demand
3. Populations and labor supply
4. Market shares
5. Wages, prices, and profits

The output block is used to calculate the final demand for goods and services produced by different sectors of the economy. Interindustry relationships are represented by an input-output model. The total economic output of a region has several parts: government spending, capital investment, exports out of the region, and the share of the local market met by regional output. State and local government spending is dependent on the regional population. The optimal level of capital stock, calculated on the basis of the relative costs of labor, capital, and fuel, drives the amount of investment in the local economy. Regional exports and the share of the local market met by the regional economy are calibrated using economic data compiled and analyzed by REMI.

The labor and capital demand block determines the amounts of capital and labor that are necessary to meet the production requirements of the output block. Labor, capital, and fuel are substituted for each other, depending on their relative

¹See Backus and Kleemann, 2000.

²See Weisbrod et al., 1995.

costs. Employment is a function of the level of output and the labor-to-output ratio for each industry, which depends on the relative costs of labor, capital, and fuel.

The population and labor supply block predicts population for 600 cohorts segmented by age, ethnicity, and gender. This block also calculates demographic processes, such as births, deaths, and aging. Predictions of labor-force participation rates are used to estimate the size of the labor force.

The market shares block estimates the share of local and external markets met by local economic output. Increases in local prices relative to national prices result in some substitution away from local suppliers to external suppliers. Reductions in profitability for local factories lead to lower production from those factories.

The wages, prices, and profits block produces estimates of wage rates, housing prices, the consumer price index, production costs, and profitability. Changes in relative employment opportunities and relative employment demand by occupation determine changes in wage rates for local markets. Wage rates affect production costs and real disposable income. Housing prices increase with population density. The consumer price index is estimated from commodity prices weighted by historical data on shares of personal consumption. Changes in production costs feed into profitability or sales price. Industries that serve local markets can adjust their sales prices in response to changes in production costs. Industries that serve external markets have less ability to set prices and become less profitable when production costs rise.

Scenario and Data Generation

To create the scenarios, we looked at two sets of interacting strategies, those that reduced electricity-generating capacity and those that replaced capacity. We examined three reduction scenarios: (1) removing the four lower Snake River hydroelectric dams, (2) reducing projected future growth in the capacity of combined-cycle power plants, and (3) a combination of both. The dams were removed by removing one dam a year for four years beginning in either 2007 or 2010. The EIA provides future estimates of planned capacity additions. For these scenarios, we reduced new combined-cycle capacity by 20 percent. We also looked at a set of specialized scenarios that addressed the DSIs (discussed below).

We examined a variety of scenarios that use mixes of solar power, wind power, and energy-efficiency measures to replace future combined-cycle generation or to

replace the four lower Snake River dams. In combinations of all three renewable technologies, solar power constitutes 20 percent, and wind and efficiency measures each constitute 40 percent of the total new capacity replaced. We looked at two key variables, the price of natural gas and the impact of technological advancement on fixed costs. We allowed the price of natural gas to vary in two ways. First, we simply used a linear increase over 20 years, with gas increasing in price from \$3/mcf to \$6/mcf. Then we used "ramped" scenarios in which the price increased from \$3/mcf to \$6/mcf by 2010 and stayed at \$6/mcf out to 2020. In the base case, natural-gas prices remain at about \$3/mcf out to 2020.

The REMI model requires data on the direct economic impacts of each scenario. These impacts come from four general sources:

1. Changes in energy rates (prices for electricity, natural gas, and fuel oil) for different classes of consumers (residential, commercial, and industrial).
2. Changes in demand for various sources of energy (electricity, natural gas, and fuel oil) used by different classes of consumers.
3. Changes in the mix of available energy sources.
4. Changes in demand for specific goods and services from specific economic sectors by both energy producers and consumers.

The data were generated in a multistep process. First, we calculated the new capacities resulting from changing the technology mix. The EIA's *Annual Energy Outlook 2001* provided net-capacity projections for 14 electricity-producing technologies,³ listed in Table A.1.

Efficiency measures were also included as an alternative technology. Hydroelectric or combined-cycle capacity could be "replaced" with more efficient appliances, better insulation, or improved industrial processes that reduce the demand for electricity. The EIA projections were for the NWPP, which includes Idaho, Oregon, Montana, and Washington, as well as Utah, Nevada, and part of Wyoming and California. To match the capacity projections with the industry sectors in REMI, we scaled the original EIA data, weighting each technology by the four-state share of total NWPP generation. The scaling factors used for each technology are shown in Table A.2.

³See EIA, 2001a, 2001d.

Table A.1
Generating Technologies Projected in
EIA Forecasts

Coal steam
Combined cycle
Nuclear power
Fuel cells
Geothermal
Biomass
Solar photovoltaic
Other fossil steam
Combustion turbine/diesel
Pumped storage
Conventional hydropower
Municipal solid waste
Solar thermal
Wind

Table A.2
Scaling Factors for Various Technologies in the Pacific
Northwest Region Relative to the NWPP

Technology	Scaling Factor (percent)
Coal Steam	29
Other fossil steam	62
Combined cycle	62
Combustion turbine	47
Nuclear power	100
Pumped storage	96
Fuel cells	77
Hydroelectric	96
Geothermal	77
Municipal solid waste	77
Biomass	77
Solar thermal	77
Solar photovoltaic	77
Wind	77

SOURCE: Energy Information Administration, "State Electricity Profiles" (available at http://www.eia.doe.gov/cneaf/electricity/st_profiles/toc.html).

For discussion purposes, the scenarios were grouped into three general cases:

1. Removing four hydroelectric dams with a total net capacity of 3.033 GW. In the scenarios, one dam was removed each year. Three of the dams had a capacity of 0.81 GW, while the last one had a capacity of 0.603 GW.
2. Replacing 20 percent of future additions of combined-cycle capacity with alternative renewable technologies and energy efficiency.
3. Exploring the effect of DSIs on the economy.⁴ In the Pacific Northwest, the primary DSI is the aluminum industry. We looked at having the aluminum industry pay market prices for electricity instead of its usual negotiated price, and the effects of having the aluminum industry continue to get a price subsidy but replacing its electricity consumption with an equivalent amount of efficiency measures.

Within each case, we ran several scenarios by varying the technology level and/or the price of natural gas.

Table A.3 shows EIA projections for combined-cycle capacity out to 2020. To replace either the dams or the new combined-cycle capacity with other technologies, we first converted those capacities to a replacement capacity. This transformation takes into account the fact that different technologies have different availability rates. For example, the availability rate for hydropower is about 41 percent, based on historical data. This means that a dam with a nameplate capacity of 0.81 GW produces a yearly average of about 0.33 GW. Table A.4 shows the availability rates for the main technologies in this study.

These same availability rates were then used to calculate the amount of new technology capacity needed. Figures A.1 and A.2 show how this works. Figure A.1 shows the baseline capacity projections for the five technologies of interest. These projections include no efficiency measures and very small capacities for solar and wind power, only about 0.12 GW each by 2020. Figure A.2 shows capacity over time when 20 percent of the new combined-cycle generation is replaced with energy efficiency and a renewable-energy mix (40 percent wind power, 40 percent energy efficiency, and 20 percent solar photovoltaic power). The total installed capacity is increased because of the differences in availabilities of the technologies. The firm power (aMW) does not change between the scenarios. The capacity projections for both scenarios are given in Table A.5.

⁴In the Pacific Northwest, the aluminum industry is the main industry identified as a DSI. The DSIs often represent only a portion of a REMI economic sector. In addition, DSIs are not distributed uniformly across the Pacific Northwest. Using Department of Commerce databases, we allocated the REMI model results to the appropriate geographic and industrial divisions.

Table A.3
**Projected Future Growth of Combined-Cycle
 Capacity**

Year	Projected Growth (GW)	20% of Growth (GW)
1999	0.00	0.00
2000	0.00	0.00
2001	0.00	0.00
2002	0.00	0.00
2003	0.00	0.00
2004	0.64	0.129
2005	0.73	0.146
2006	0.64	0.130
2007	0.57	0.115
2008	0.42	0.084
2009	0.62	0.125
2010	0.64	0.129
2011	0.86	0.174
2012	0.50	0.101
2013	0.14	0.027
2014	0.59	0.119
2015	0.26	0.053
2016	0.46	0.093
2017	0.43	0.087
2018	0.41	0.083
2019	0.48	0.096
2020	0.47	0.094

^aEIA, *Annual Energy Outlook 2001*, scaled
 for the four states.

Table A.4
Availability Rates for Various Technologies

Technology	Availability Rate
Combined cycle	0.75
Conventional hydropower	0.41
Solar photovoltaic	0.3
Wind	0.25
Efficiency measures	1

SOURCE: DynCorp, 1995.

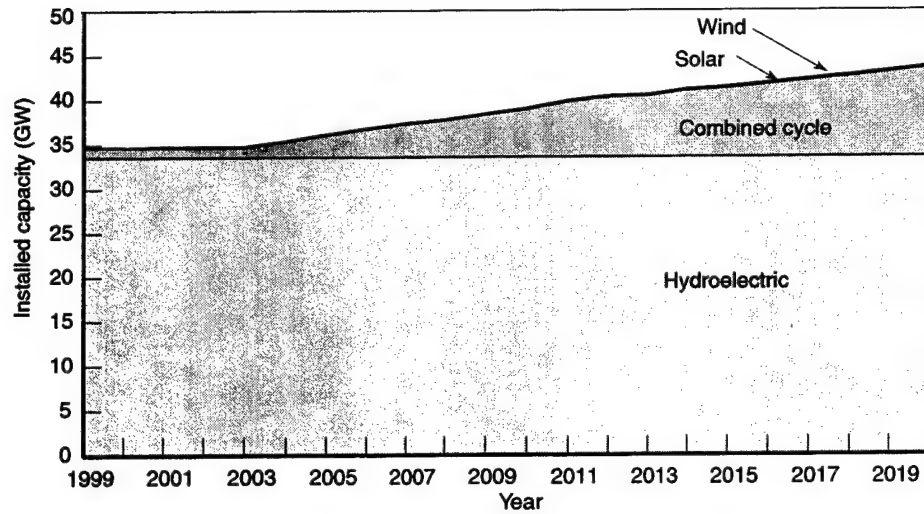


Figure A.1—EIA Projections of Future Installed Capacity in the Pacific Northwest

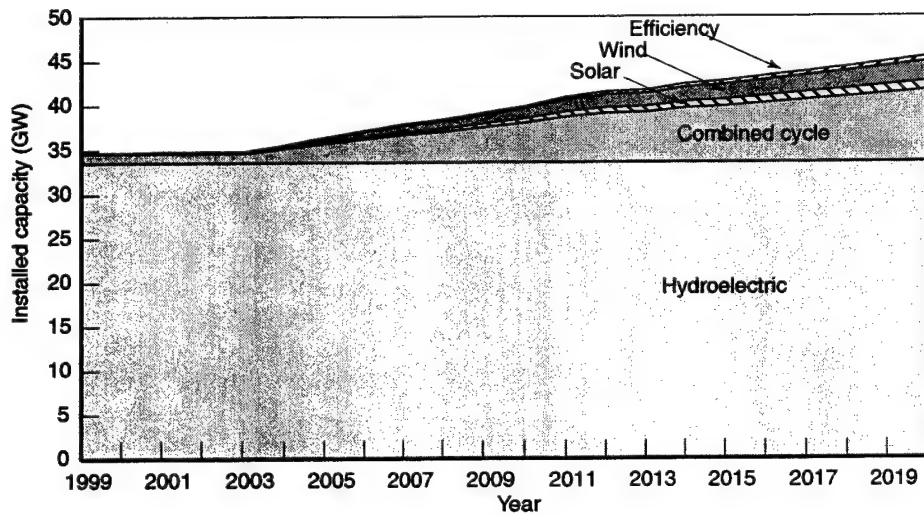


Figure A.2—Projections of Future Capacity with 20 Percent of New Combined-Cycle Generation Replaced with a Mix of Energy Efficiency, Wind Power, and Solar Photovoltaic Power

Table A.5

EIA Capacity Projections^a and Projections for Replacing 20 Percent of New Combined-Cycle Capacity with Energy Efficiency, Wind Power, and Solar Photovoltaic Power

Technology	EIA Projected Capacity in 2020 (GW)	Capacity in 2020 with 20 Percent of New Combined Cycle Replaced with Energy Efficiency, Wind Power, and Solar Power (GW)
Combined cycle	9.95	8.17
Hydroelectric	33.6	33.6
Solar photovoltaic	0.116	1.01
Wind	0.123	2.26
Energy efficiency	NA	0.535

^aProjections of the NWPP scaled for the four states in the study, based on state-level data provided by the EIA.

The second step in generating the data was to calculate the various fixed and operating and maintenance (O&M) costs in dollars per kilowatt. There is a total fixed cost and an O&M cost associated with each technology. These costs are further broken down for each technology by an impact analysis for planning (IMPLAN) code. The costs and corresponding IMPLAN codes for each technology are taken from DynCorp (1995).⁵ REMI uses these codes to assign costs to particular industry groups. For example, the O&M costs for combined cycle correspond to wholesale trade, chemicals and allied products, and other transportation and transportation services. Table A.6 shows the O&M costs associated with combined-cycle, solar, and wind technologies, and Table A.7 presents the fixed costs.

The fixed costs for combined-cycle generation, solar power, and wind power were amortized over 30 years with a 5 percent discount rate, while energy-efficiency fixed costs were amortized over 10 years with a 5 percent discount rate. The industry purchasing the new technologies uses these amortized values, while the industries from which the technologies are purchased use the regular fixed costs, counting the purchases as revenue for the year in which they were purchased.

⁵The DynCorp report is discussed in detail in Appendix C.

Table A.6
O&M Costs for Various Technologies

Technology/Industry Sector	IMPLAN Code	O&M Costs (\$/kW)
Combined cycle		
Engineer supervision	508	3
Boiler plate	284	9
Other	443	19
Natural gas	444	101
Solar power		
Array cleaning and plant operations	443	11
Array—materials	377	14
Array—labor	506	7.4
Power conditioning unit—materials	360	7.6
Power conditioning unit—labor	506	3.6
Wind power		
Engineer supervision	508	7
Other	443	2
Machine routine maintenance	472	5
Emergency repairs	506	2
Parts inventory fund—major component	307	5

SOURCE: DynCorp, 1995.

Table A.7
Fixed Costs for Various Technologies

Technology/Industry Sector	IMPLAN Code	Fixed Costs (\$/kW)
Combined cycle		
Combustion turbine AUX	307	180
Steam generator	284	65
Steam turbine	307	58
Fuel handling facilities	284	5
Balance of plant	50	196
Engineering and construction management	506	56
Solar power		
Modules	377	2,262
Array structure	282	540
Power conditioning unit	360	528
Installation and facility expenses	50	780
Engineering and construction management	506	1,080
Wind power		
Turbine (rotor, blades, housing, drive)	307	557
Tower	282	113
Balance of system	50	106
Engineering and construction management	506	237
Transmission and distribution infrastructure	T&D	70
Efficiency measures		2,000

SOURCE: DynCorp, 1995.

The IMPLAN codes are mapped to the REMI model as shown in Table A.8. Almost all adjustments to industry demand assume that the demand will be split between regional Pacific Northwest production and imports from the rest of the country. The REMI model allocates demand changes between regional production and imports by using a regional purchase coefficient (RPC) estimated for each industry sector, based on historical data. The only industry sector for which we modified this assumption was the natural-gas sector. Almost all of the natural gas used in the Pacific Northwest is produced outside of the region. Because the natural-gas extraction industry is aggregated within the mining sector, demand changes would have been split using an RPC of 32 percent, instead of an RPC of 0 percent, which more accurately reflects the natural-gas-extraction sector. We set the RPC for the mining sector to 0 percent for scenario runs that involved reductions in demand for natural gas, forcing all reductions to come out of imports.

In the scenarios involving the removal of the hydroelectric dams, more information was required than just the usual fixed costs: These scenarios also required estimates of the costs for removing the dams.⁶ Table A.9 outlines the major costs and benefits anticipated from the removal.⁷

Table A.8
Conversion of IMPLAN Codes to REMI Codes

IMPLAN Code	REMI Code
50 New Utility Structures	23 Construction
282 Fabricated Structural Metal	5 Fabricated Metal Products
284 Fabricated Plate Work (Boiler Shop)	5 Fabricated Metal Products
307 Steam Engines and Turbines	6 Machinery and computer equipment
360 Electrical Industrial Apparatus	7 Electrical equipment, exp.computers
377 Semiconductors and Related Devices	7 Electrical equipment, exp.computers
443 Electric Services	30 Electric, gas, and sanitary services
444 Gas Production and Distribution	22 Mining
472 Services to Buildings	42 Business Services
506 Engineering, Architectural Services	46 Legal, engineering, and management services
508 Management and Consulting Services	46 Legal, engineering, and management services
T&D	23 Construction

⁶See Foster Wheeler, 1999.

⁷The costs used in the study and their origins are discussed in detail in Appendix B.

Table A.9
Costs and Benefits Associated with Lower Snake River Dam Removal

Activity	Cost/Benefit
Reservoir recreation	Forgone revenues to the region from removing the dams
Grain transportation	Costs due to higher transportation costs
Other commodities transportation	New costs to other commodities
Farmland	Reduced value of farmland due to loss of irrigation
Municipal and industrial pump stations	Costs associated with providing new sources of water
Privately owned wells	Costs associated with new sources of water
River recreation	Calculated benefits from new types of recreation along the river
Recreational fishing	Calculated benefits from increased recreational fishing
Commercial fishing	Benefits associated with increased commercial fishing
Anadromous Fish Evaluation Program	Avoided costs from discontinuing the program
Turbine rehabilitation	Avoided costs of having to maintain the dam turbines
Nonproject OMRR&R ^a	Avoided yearly maintenance costs of the dams
Surplus property	
Investment costs	One-time costs associated with dam removal
OMRR&R ^a costs	O&R Costs associated with dam removal, entered as a single-year cost

^aOperation, maintenance, repair, replacement, and rehabilitation.

In some scenarios, the fixed costs for solar power and wind power were also affected by the level of technology. We assumed that future advancements in these technologies could lower the expected fixed costs.⁸ Figure A.3 shows the three technological-advancement levels and the associated costs for each technology. In the low-technology scenarios, solar-power fixed costs decreased by 20 percent between 2000 and 2020, while wind-power fixed costs decreased by 10 percent. In the average-technology scenarios, the corresponding rates were 40 percent and 20 percent; and in the high-technology scenario, the rates were 60 percent and 30 percent. For energy efficiency, a cost of \$2,000/kW (approximately 3¢/kWh) is assumed for the base case, and a cost of \$1,000/kW (approximately 1.5¢/kWh) is assumed for the advanced-technology case.

⁸Advances for combined-cycle generation were neglected in the advanced-technology analysis because of the difference in its progress ratios (i.e., the corresponding change in price for the doubling of cumulative volume) relative to those of the other technologies. For instance, the progress ratios for wind (82 percent) and solar photovoltaic (65 percent) are much more dramatic than those for combined cycle (96 percent) and supercritical coal (97 percent) (see International Energy Agency, 2000).

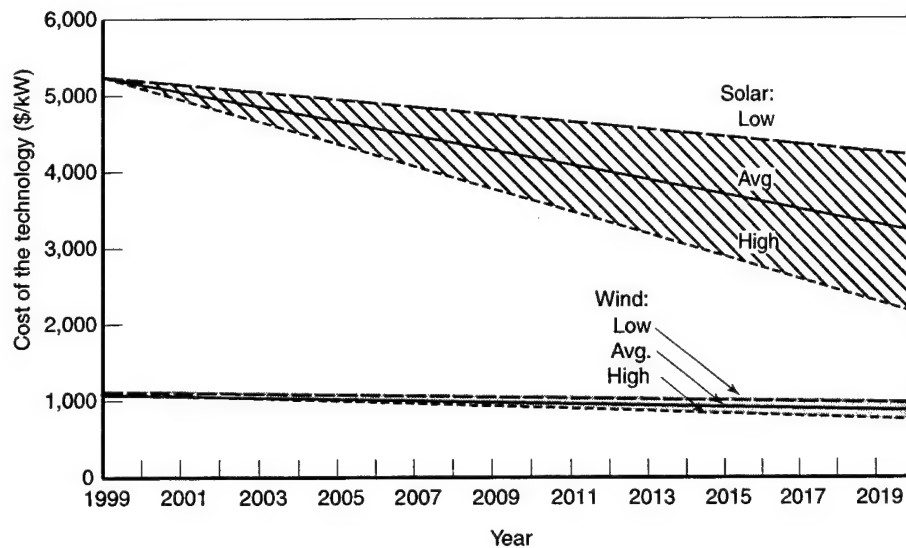


Figure A.3—Costs of Technology Improvements for Low-, Average-, and High-Technology Cases

Finally, we used two assumptions concerning the price of natural gas. In the base case, we assumed a constant cost of \$3/mcf for gas (in real terms) out to 2020. In the other scenarios, we assumed that the price of gas began at \$3/mcf in 2000 and then increased linearly to \$6/mcf in 2010, where it remained through 2020. The price of natural gas affects the O&M costs of any technologies that use it, e.g., combined cycle and fossil steam. These costs are identified by an IMPLAN code that is linked to the transportation industry sector.

We calculated the difference between the baseline costs and the scenario costs generated by applying the reduction and replacement mixes. The data were grouped by IMPLAN code, which REMI feeds into the appropriate industry sector.

The third step in the data-generation process involved estimating changes in electricity prices. For each technology, we estimated a total cost of production, based on the fixed and O&M costs calculated above. The cost for each technology was then weighted by its market share (based on net capacity), and the costs were summed to create a predicted electricity "price." We created a percentage change in price from the base case as described above. Applying the reduction and replacement scenarios then created a new set of expected prices. We report the percentage change between the new prices and the base case prices for every year.

The REMI model is highly aggregated, with the entire national economy separated into only 53 economic sectors and two geographic regions—the Pacific Northwest and the rest of the United States. The collected data must be aggregated to the same levels as those represented in the model. Data collected on a per-firm basis were aggregated to appropriate industry and regional levels by using business and industry statistics in the *County Business Patterns* and the *Statistics of U.S. Business* published by the U.S. Department of Commerce.

Once the data were aggregated, the impacts were assigned to appropriate REMI policy variables. Table A.10 describes the policy variables used for each scenario.

Table A.10

REMI Policy Variables Used in Analysis of Impacts on Electricity Producers and Consumers

Remove dams and replace 1250 aMW of hydroelectricity with 1250 aMW of natural-gas generation

REMI Policy Variable	Types of Data
Impacts on electricity producers	
Industry Demand for 49 Industrial Sectors	Purchases of dam removal services. Purchases of new natural gas electric power generation (equipment and construction). Additional natural gas purchases by utilities for new generation.
Labor or Factor Productivity	Changes in employees per unit of output or the total labor and capital used per unit of output in electricity generation.
Capital Costs	Additional capital spending on combined cycle.
Impacts on electricity consumers	
Electricity Fuel Costs	Changes in electricity prices for commercial, industrial, and residential customers due to change in generation mix. Can also be broken down by 49 separate industries.
Natural Gas Fuel Costs	Changes in Northwest natural gas prices due to increased demand. Prices are determined exogenously, so if the change in prices is believed to be significant, we must enter it ourselves.

Table A.10 (continued)

Remove dams and replace 1250 aMW of hydroelectricity with 1250 aMW of renewables and energy-efficiency mixes

REMI Policy Variable	Types of Data
Impacts on electricity producers	
Industry Demand for 49 Industrial Sectors	Purchases of dam removal. Purchases of new renewable generation (equipment and construction).
Labor or Factor Productivity	Changes in employees per unit of output or the total labor and capital used per unit of output in electricity generation.
Electric Utilities Sales	Reduced sales for electric utilities (unless offset by sales of energy efficiency service sales by utilities).
Capital Costs	Additional capital spending on renewable generation.
Impacts on electricity consumers	
Electricity Fuel Costs	Changes in electricity prices for commercial, industrial, and residential customers due to change in generation mix. Can also be broken down by 49 separate industries.
Industry Demand for 49 Industrial Sectors	New purchases of electrical equipment and gas appliances, building and insulation materials, and installation and engineering services.
Capital Costs	Increases in capital spending for energy efficient equipment.

Replace a portion of future natural-gas combined-cycle generation with renewables and energy-efficiency mixes

REMI Policy Variable	Types of Data
Impacts on electricity producers	
Industry Demand for 49 Industrial Sectors	Purchases of new renewable generation (equipment and construction).
Labor or Factor Productivity	Changes in employees per unit of output or the total labor and capital used per unit of output in electricity generation.
Electric Utilities Sales	Reduced sales for electric utilities (unless offset by sales of energy efficiency service sales by utilities).
Capital Costs	Additional capital spending on renewable generation and energy efficiency equipment.
Impacts on electricity consumers	
Electricity Fuel Costs	Changes in electricity prices for commercial, industrial, and residential customers due to change in generation mix. Can also be broken down by 49 separate industries.
Industry Demand for 49 Industrial Sectors	New purchases of electrical equipment and gas appliances, building and insulation materials, and installation and engineering services.
Capital Costs	Increases in capital spending for energy efficient equipment.

Table A.10 (continued)

Have DSIs pay market prices for electricity

REMI Policy Variable	Types of Data
	Impacts on electricity producers
Electric Utilities Sales	Increased sales for electric utilities.
	Impacts on electricity consumers
Electricity Fuel Costs	Increased electricity costs for DSI industry sectors.

Keep DSI subsidy and replace new DSI consumption with energy efficiency

REMI Policy Variable	Types of Data
	Impacts on electricity producers
Electric Utilities Sales	Reduced sales for electric utilities (unless offset by sales of energy efficiency service sales by utilities).
	Impacts on electricity consumers
Industry Demand for 49 Industrial Sectors	New purchases of electrical equipment and gas appliances, building and insulation materials, and installation and engineering services.
Capital Costs	Additional capital spending on energy efficient equipment.

Interpretation of Results

After we assigned the data to the appropriate policy variables, the REMI model was run to produce a set of results. These results were produced at the same level of aggregation as the inputs and had to be disaggregated. We disaggregated them using the same Department of Commerce databases that were used to aggregate the input data, as required. For example, the regional employment results for the Pacific Northwest were disaggregated to produce results for each state in the region, using the percentage share of total regional employment for each state. Disaggregating to more-detailed industry sectors can be performed in a similar manner. Forecasts are reported for changes in employment, industry output, and industry value-added. REMI defines the value-added of an industry as the value of its output minus the value of its material inputs. Value-added consists of labor, capital, and fuel inputs. When the value-added contributions for all the industries in a region are summed, the result is the gross regional product.

B. Estimated Costs and Benefits from Removing the Lower Snake River Dams

This appendix describes the study from which we obtained the majority of the cost data on the removal of the four lower Snake River dams (Foster Wheeler, 1999).

Study Assumptions

A 100-year period of analysis was used to assess all project impacts. The base year for the analysis was fiscal year 1998, but the 100-year period extends from the implementation year (2005) through 2104. Benefits and costs incurred during the period of analysis are discounted to the beginning of 2005. The costs and benefits are converted into 1998 dollars and annualized to provide an average annual value for each alternative. Three different discount rates were used: 6.875 percent, 4.75 percent, and 0 percent.

The Foster Wheeler study looked at four alternatives, but we are concerned with only two. Alternative 1, existing conditions, is the status quo. Alternative 4, dam breaching, allows the reservoirs to be drained, resulting in a free-flowing river. This would involve removing the earthen embankment sections of the four dams, then developing a channel around the powerhouses, spillways, and navigation locks. Navigation locks would no longer be operational, and navigation for large commercial vessels would be eliminated. Some recreation facilities would close, others would be modified, and new facilities could be built in the future.

The study reported national economic development (NED) costs and benefits, i.e., the decrease or increase in the value of the national output of goods and services, expressed in dollars. NED figures reflect costs and benefits to the nation and not to a particular region. They address power, recreation, transportation, water supply, commercial fishing, some tribal issues, flood control, and implementation/avoided costs.

Power

For the dam-breaching alternative, the study used three economic costs:

1. A point estimate of system costs, \$238 million.
2. A point estimate of transmission reliability costs, \$25 million.
3. An estimate of ancillary service costs, \$8 million.

Total annual net economic costs were calculated to be \$271 million. We, however, used our own calculations of the cost of power, the effects of power choice on the price of electricity, and other factors described elsewhere in the study.

Recreation and Tourism

The Foster Wheeler study used five surveys to identify and value recreation use. Existing reservoir use and annual benefits consisted of 500,172 trips worth \$33,254,000. Existing recreation use consisted of 640,685 trips worth \$38,524,000 a year. Future use was generated from a composite of high and low estimates.

Transportation

Transportation costs are the costs for commodities currently transported by barge on the lower Snake River that would need to be shipped by rail or truck. Direct economic effects were measured in terms of opportunity costs rather than market rates. A perfectly competitive market was assumed, and possible increases in rail and truck transportation rates were not taken into account. The majority of the average annual cost increase, about 83 percent, would be associated with grain.

Water Supply

Breaching the dams would directly affect the operation of river pump stations and wells used for irrigation and other activities. Approximately 37,000 acres of irrigated farmland currently rely on water pumped from the Ice Harbor Reservoir. Additional farmland is irrigated by private wells. The cost of modifying the Ice Harbor pumping stations to provide current water supplies would be more than twice the value of the land they currently irrigate.

The municipal and industrial pump stations that draw from the lower Snake River are all located on the lower Granite Reservoir. These are used for water-system backup, golf-course irrigation, industrial process water for paper production, and concrete-aggregate washing. The costs in the analysis are estimates of what it would take to modify these systems. The Army Corps of Engineers also estimates that 95 (40 percent) of the wells within 0.6 km of the river would require modification in the dam-breaching case. Using a 0 percent discount rate results in average annual costs ranging from \$2,021,900 to \$4,458,900.

Anadromous Fish

The study also looked at the economic costs associated with changes in the commercial and ocean recreational fish harvest, using a process called Plan for Analyzing and Testing Hypotheses (PATH). The analysis provided data for seven stocks of spring/summer chinook salmon, a review of fall chinook, and an evaluation of the correlation between chinook and steelhead. The analysis included all Snake River wild and hatchery stocks. Most of the benefits are associated with in-river treaty fishery contributed by fall chinook and in-river recreational fishery. Under the 0 percent discount rate, the net economic impact was a benefit of \$3,485,740.

Implementation/Avoided Costs

The implementation costs included all project-related construction and acquisition costs and OMRR&R costs. The major categories are

- Construction costs for breaching the dams, including wildlife and cultural-resources protection and mitigation at each of the dams.
- Interest during construction.
- Anadromous Fish Evaluation Program.
- OMRR&R costs associated with new fish-habitat improvement projects, such as the purchase of water.

These costs are listed in Table B.1. The study estimated average annual economic effects of the dam-breaching scenario (0 percent discount rate) to be \$8,298,000.

Table B.1
Implementation Costs of Dam Removal

Activity	Dam Removal Cost (\$/kW)
Reservoir recreation	52.5
Grain transportation	38.5
Other commodities transportation	8.1
Farmland	2.2
Municipal and industrial pump stations	0.6
Privately owned wells	0.9
River recreation	188.2
Recreational fishing	54
Commercial fishing	5.8
Anadromous Fish Evaluation Program	1.2
Turbine rehabilitation	6.4
Non-project OMRR&R	41.6
Surplus property	0.2
Investment costs	13.6
OMRR&R costs	1.4

The avoided costs include costs that would no longer be required to operate and maintain the lower Snake River dams and associated lands, such as costs associated with major upgrades, including major improvements to fish bypass; future annual O&M costs and repair costs associated with maintaining the dams; and disposition of equipment that would no longer be needed. The study estimated the avoided costs per year for the dam-breaching alternative to be \$29,050,000. The costs and benefits of removing the dams are summarized in Table B.2.

Table B.2
Costs and Benefits of Removing the Lower Snake River Dams

Item	Average Annual Economic Effects, 0% Discount Rate	Total Economic Effects (\$)	Yearly Values, 5% Discount Rate over 100 Years	Value (\$/kW)
Costs				
Recreation and tourism				
Reservoir recreation	\$31,600	\$3,160,000,000	\$159,210,716	52.49
Transportation				
Grain	\$23,156	\$2,315,600,000	\$116,667,195	38.467
Non-grain commodities	\$4,904	\$490,400,000	\$24,707,891	8.15
Water supply				
Loss of irrigated farmland value	\$1,342	\$134,240,000	\$6,763,432	2.23
Municipal and industrial pump stations	\$334	\$33,350,000	\$1,680,278	0.55
Privately owned wells	\$565	\$56,450,000	\$2,844,128	0.94
Implementation costs				
Investment cost	\$8,218	\$821,800,000	\$41,404,863	13.65
OMRR&R cost	\$813	\$81,300,000	\$4,096,149	1.35
Benefits				
Recreation and tourism				
River recreation	\$113,300	\$11,330,000,000	\$570,840,954	188.21
Recreational fishing	\$32,485	\$3,248,500,000	\$163,669,624	53.96
Anadromous fish				
Commercial, ocean	\$736	\$73,590,000	\$3,707,695	1.22
Commercial, in river	\$2,543	\$254,308,000	\$12,812,835	4.22
Recreational, ocean	\$207	\$20,676,000	\$1,041,722	0.34
Implementation costs				
Anadromous Fish Evaluation Program	\$733	\$73,300,000	\$3,693,084	1.22
Avoided costs				
Turbine rehabilitation	\$3,871	\$387,100,000	\$19,503,313	6.43
Non-project-related OMRR&R	\$25,030	\$2,503,000,000	\$126,108,995	41.58
Surplus property	\$149	\$14,900,000	\$750,709	0.25

C. Cost Breakdowns of Power-Generation Technologies

Cost breakdowns of the technologies were taken primarily from DynCorp (1995). This appendix discusses the origin of the data.

The DynCorp study analyzed the effects on the economy and on employment of deploying renewable technologies in two regions, Texas and Washington/Oregon. It looked at changes in level of employment, the effects on various industries, and changes in economic activity by simulating the addition of renewable resources to the energy-generation mix. Renewable-resource availability, capital and O&M expenditures, and project utility capacity and overall electricity growth trends were included to account for the value of net-employment losses and gains. The IMPLAN economic input-output model was used to predict future economic and employment changes.

IMPLAN, an economic analysis system produced by the Minnesota IMPLAN Group, has two components: data files and software. The data files include information on 528 industries that are linked to four-digit standard industrial classification (SIC) codes. Table C.1 shows the relationships used in the DynCorp report.

Technology characterizations are given for 10 electrical-generation plants. Capital expenditures for new plant construction investments were estimated using standard costs for typical facilities. These included all the costs associated with the building of a new electric-power-generation facility: direct labor, equipment, site preparation, buildings, tools, installation, architecture, and design services. The O&M costs include the average yearly range of fixed and variable expenditures for equipment replacement, labor, fuel, and administration of plant operations. All O&M costs were calculated based on a 30-year operating life.

Most of the costs were obtained from the *Technical Assessment Guide* of the Electric Power Research Institute (EPRI).

Table C.1
IMPLAN Sectors and Corresponding SIC Codes

No.	1990 IMPLAN Database Sector	SIC Code
37	Forestry Products	0810, 0830, 0970
38	Coal Mining	1200
50	Natural Gas & Crude Petroleum	1310
50	New Utility Services	Part of 15, 16, 17
230	Glass and Glass Products, exc. Containers	3172
244	Ready-Mixed Concrete	3271
282	Fabricated Structural Metal	3441
284	Fabricated Plate Work (Boiler Shops)	3443
307	Steam Engines and Turbines	3511
315	Conveyors and Conveying Equipment	3535
331	Special Industry Machinery, NEC	3559
332	Pumps and Compressors	3561, 3563
338	General Industrial Machinery, NEC	3569
347	Refrigeration and Heating Equipment	3585
360	Electrical Industrial Apparatus, NEC	3629
377	Semiconductors and Related Devices	3674
403	Mechanical Measuring Devices	3823, 3824, 3829
443	Electric Services	4910, and part of 4789
444	Gas Production and Distribution	4920, part of 4789
446	Sanitary Services and Steam Supply	4953, 4959, 4960, 4970
472	Services to Buildings	7340
506	Engineering, Architectural Services	8710
508	Management and Consulting Services	8740
524	Rest of the World Industry	N/A

Photovoltaic Flat-Plate, Fixed-Array System

The numbers assume the use of crystalline-silicon-cell technology, which represented the largest installed base at the time of the DynCorp study. Performance was modeled using a flat-plate fixed array with a 500-kW nameplate capacity, without battery storage. Plant costs include the photovoltaic modules, array structure, power-conditioning unit, installation and facility expense, and engineering and construction management. O&M costs include array-cleaning and plant-operations cost, repair, maintenance, and labor costs of the array and power-conditioning unit. The balance of the plant system includes maintenance buildings, fences, drainage, and other required ancillary systems.

The IMPLAN codes and costs of solar photovoltaic generation are given in Table C.2.

Table C.2
IMPLAN Codes and Costs of Solar Photovoltaic
Generation

IMPLAN Code	Cost (\$/kW)	Adjusted Cost (\$/kW)
O&M Costs		
443	11	11
377	14	14
506	7.4	7.4
360	7.6	7.6
506	3.6	3.6
Fixed Costs ^a		
377	3,770	2,262
282	900	540
360	880	528
50	1,300	780
506	1,800	1,080

^aFixed costs were adjusted downward in our study by 40 percent to reflect the current state of the art. (See EIA, 2002c, for technology costs used in *Annual Energy Outlook 2002*.) Recall that sensitivity to these prices is reflected in the comparison of the base-technology case with the advanced-technology case (40 percent reduction in capital prices of solar photovoltaics over the study period for the base case). Relative allocation to IMPLAN codes was kept constant.

Horizontal Wind Turbines

The wind farm in the model consisted of 143 large turbines rated at 350 kW each. Total construction cost for each unit included the turbine, tower, foundation, balance of system, engineering, and construction. The total O&M costs included general facilities O&M, routine machine maintenance, emergency repairs, and parts inventory fund. The cost information, presented in Table C.3, was obtained from the American Wind Energy Association and EPRI's *Technical Assessment Guide*.

Table C.3
IMPLAN Codes and Costs of Wind
Generation

IMPLAN Code	Cost (\$/kW)
O&M Costs	
508	7
443	2
472	5
506	2
307	5
Fixed Costs	
307	557
282	113
50	106

Conventional Gas-Fired Combined-Cycle System

The plant used in the model is a 225-MW unit consisting of two combustion turbines driving a steam cycle. The plant operates at a heat rate of 7,520 Btu, with a capacity factor of 70 percent. This is classified as an intermediate or even a base-load unit. The steam cycle is similar to that used in fossil-fueled steam plants. The cost estimates, given in Table C.4, come from EPRI's *Technical Assessment Guide*.

Table C.4
IMPLAN Codes and Costs of
Combined-Cycle Generation

IMPLAN Code	Cost (\$/kW)
O&M Costs	
508	3
284	9
443	19
444	101
Fixed Costs	
307	180
284	65
307	58
284	5
50	196
506	56

Bibliography

- Awerbuch, Shimon (1996). *How to Value Renewable Energy: A Handbook for State Energy Officials*, Interstate Renewable Energy Council, Latham, NY, March (available at www.irecusa.org/).
- Awerbuch, Shimon, Jesse Dillard, Tom Mouck, and Alistair Preston (1996). "Capital Budgeting, Technological Innovation and the Emerging Competitive Environment of the Electric Power Industry," *Energy Policy*, Vol. 24, No. 2, February.
- Backus, George, and Susan Kleemann (2000). *Impacts of Aluminum Industry Closings on the Pacific Northwest*, prepared for the Aluminum Industry Study Group (available at http://www.bpa.gov/power/pl/aluminumstudy/Al_Econ_Study.pdf).
- DynCorp Environmental, Energy & National Security Programs (1995). *An Assessment of the Regional Economic and Employment Impacts of the Commercialization of Renewable Technologies*, prepared for the National Renewable Energy Laboratory, Alexandria, VA.
- Electric Power Research Institute (EPRI). *Technical Assessment Guide* (update available at www.epri.com).
- Energy Information Administration (1995). *Measuring Energy Efficiency in the United States Economy: A Beginning*, March.
- ____ (2001a). *Annual Energy Outlook 2001*, Table 69, Electric Power Projections for Electricity Market Module Region Western Systems Coordinating Council/Northwest Power Pool Area, AEO Supplement Reference Case Forecast.
- ____ (2001b). *Annual Energy Outlook 2001*, Table 69, Electric Power Projections for EMM Region (1 of 3) Western Systems Coordinating Council/Northwest Power Pool Area, Supplementary Tables.
- ____ (2001c). *Annual Energy Outlook 2001*, Table 72, Renewable Energy Generation by Fuel Western Systems Coordinating Council/Northwest Power Pool Area, AEO Supplement Reference Case Forecast.
- ____ (2001d). *Annual Energy Outlook 2001*, Table 76, Renewable Resource Generating Capacity by EMM Region and Source (3 of 3), Supplementary Tables.
- ____ (2002a). *Annual Energy Outlook 2002, Impacts of a 10-Percent Renewable Portfolio Standard*, SR/OIAF/2002-3, February.
- ____ (2002b). *Annual Energy Outlook 2002*, Table 23, Comparison of Natural Gas Forecasts, DOE/EIA-0383.

- _____. (2002c). *Annual Energy Outlook 2002*, Table 38, Assumptions to Annual Energy Outlook 2002, DOE/EIA-0554.
- Environmental Protection Agency (2000). E-GRID (available at www.epa.gov).
- Foster Wheeler Environmental Corporation (1999). "Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement," Appendix I, Draft, December.
- International Energy Agency (2000). *Experience Curves for Energy Technology Policy* (available at <http://www.iea.org/public/studies/curves.htm>).
- Kydes, Andy S. (1999). *Modeling Technology Learning in the National Energy Modeling System*, Energy Information Administration, EIA/DOE-0607.
- Mapes, Lynda V. (1999). "The Debate over the Snake River Dams," *The Seattle Times*, November 28.
- Northwest Power Planning Council (1998). *Revised Fourth Northwest Conservation and Electric Power Plan*, Document 98-22.
- "RAND California Databases" (2002). RAND, Santa Monica, CA (available at <http://www.ca.rand.org>).
- Regional Economic Models, Inc. (nd). *REMI Policy Insight User Guide*, Version 3.0 (see <http://www.remi.com/Overview/Structure/structure.html>).
- Roberts, Peter A., Ingrid S. Harrison, John L. Reinertsen, and Morris Margolis (1995). *An Assessment of the Regional Economic and Employment Impacts of the Commercialization of Renewable Technologies*, DynCorp Environmental, Energy & National Security Programs, Alexandria, VA, June 27.
- Spath, Pamela L., and Margaret K. Mann (2000). *Life Cycle Assessment of a Natural Gas Combined-Cycle Power Generation System*, National Renewable Energy Laboratory, NREL/TP-570-27715, September.
- Treyz, Frederick, and Lisa Petraglia (1997). "Forecasting the Effects of Electric Utility Deregulation: A Hypothetical Scenario for New Jersey," *The Journal of Business Forecasting*, Summer, pp. 5-7.
- Treyz, G. I. (1993). *Regional Economic Modeling: A Systematic Approach to Economic Forecasting and Policy Analysis*, Kluwer Academic Publishers, Boston, MA.
- U.S. Army Corps of Engineers (1999). *Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement*, Appendix G.
- Washington State Office of Trade and Economic Development (2001). *Convergence: Natural Gas and Electricity in Washington*, Energy Policy Division, May.
- Weisbrod, Glen, Karen Polenske, Teresa Lynch, and Xianuan Lin (1995). *Final Report: The Economic Impact of Energy Efficiency Programs and Renewable Power for Iowa*, prepared for Iowa Department of Natural Resources, December.